# INSTITUTION

OF

# MECHANICAL ENGINEERS.

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## PROCEEDINGS.

## 1869.

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## President.

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## Past-Presidents.

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Sir Joseph Whitworth, Bart., . Manchester.

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Thomas Hawksley, . . . London.
Sampson Lloyd, . . . Wednesbury.
John Ramsbottom, . . . Crewe.
C. William Siemens, . . London.

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William Clay, . . . . Birkenhead.
Charles Cochrane, . . . Dudley.
Edward A. Cowper, . . London.
John Fernie, . . . . Leeds.
Sir Charles Fox, . . . London.
Edgar Gilkes, . . . . Middlesbrough.
Thomas Greenwood, . . Leeds.
George Harrison, . . . Birkenhead.
Walter May, . . . . Birmingham.
William Menelaus, . . . Merthyr Tydvil.
W. Montgomerie Neilson, . Glasgow.
John Robinson, . . . . Manchester.
Charles P. Stewart, . . Manchester.
Percy G. B. Westmacott, . . Newcastle-on-Tyne.

## Treasurer.

Henry Edmunds,
*Birmingham and Midland Bank, Birmingham.*

## Secretary.

William P. Marshall.

## Assistant Secretary.

Alfred Bache,
*Institution of Mechanical Engineers,*
81 *Newhall Street, Birmingham.*

# LIST OF MEMBERS,

WITH YEAR OF ELECTION.

## 1869.

### MEMBERS.

1861. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.
1848. Adams, William Alexander, Newbold Beeches, Leamington.
1859. Adamson, Daniel, Newton Moor Iron Works, Hyde, near Manchester.
1861. Addenbrooke, George, Rough Hay Furnaces, Darlaston, near Wednesbury.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt, Oise, France.
1847. Allan, Alexander, Bridge Street, Worcester.
1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.
1865. Alleyne, John Gay Newton, Butterley Iron Works, Alfreton.
1867. Allibon, George, Rosherville Iron Works, Northfleet, near Gravesend.
1859. Alton, George, Midland Road, Derby.
1861. Amos, Charles Edwards, 5 Cedars Road, Clapham Common, London, S.W.
1867. Amos, James Chapman, Grove Works, Southwark Street, London, S.E.
1856. Anderson, John, Superintendent of Machinery to the War Department Royal Arsenal, Woolwich, S.E.
1856. Anderson, William, Erith Iron Works, Erith, London, S.E.
1862. Angus, Robert, Locomotive Superintendent, North Staffordshire Railway, Stoke-upon-Trent.
1858. Appleby, Charles Edward, Renishaw Colliery, near Chesterfield.
1867. Appleby, Charles James, Emerson Street, Southwark, London, S.E.
1859. Armitage, William James, Farnley Iron Works, Leeds.
1866. Armstrong, George, Great Western Railway, Locomotive Department, Wolverhampton.
1863. Armstrong, John, Timber Works, 17 North Bridge Street, Sunderland.
1857. Armstrong, Joseph, Locomotive Superintendent, Great Western Railway, Swindon.
1858. Armstrong, Sir William George, C.B., Elswick, Newcastle-on-Tyne.
1857. Ashbury, James Lloyd, 9 Sussex Place, Hyde Park Gardens, London, W.
1869. Austin, William Lawson, Cambria Steel and File Works, Sheffield.
1869. Aveling, Thomas, Messrs. Aveling and Porter, Rochester.

1865. Bagshawe, John J., Thames Steel Works, Sheffield.
1865. Bailey, John, Blackhall Place Iron Works, Dublin.
1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.
1866. Baines, William, London Works, Soho, near Birmingham.
1866. Baker, Samuel, 22 Oil Street, Liverpool.
1865. Baldwin, Martin, Bovereux Iron Works, Bilston.
1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.
1866. Barker, George, Messrs. Barker and Cope, Kidsgrove, Stoke-upon-Trent.
1860. Barker, Paul, Old Park Iron Works, Wednesbury.
1866. Barnard, Clement, 11 Billiter Square, London, E.C.
1862. Barrow, Joseph, Whalley Chambers, 88 King Street, Manchester.
1867. Barrows, Thomas Welch, Portable Engine Works, Banbury.
1862. Barton, Edward, Carnforth Hæmatite Iron Works, Carnforth, near Lancaster.
1865. Bass, William, Sanitary Pipe Works, Parkgate, near Rotherham.
1860. Batho, William Fothergill, 36 Lancaster Street, Birmingham.
1859. Beacock, Robert, Victoria Foundry, Leeds.
1865. Beardshaw, Charles C., Baltic Steel Works, Sheffield.
1848. Beattie, Joseph, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.
1869. Beattie, William George, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.
1867. Beaumont, Captain Frederick, R.E., Royal Engineer Office, Sheerness.
1859. Beck, Edward, Messrs. Neild and Co., Dallam Iron Works, Warrington. (*Life Member.*)
1862. Beckett, Henry, Mining Engineer, Upper Penn, Wolverhampton.
1864. Beckton, James George, Whitby, Yorkshire.
1865. Bell, Charles, North Staffordshire Railway, Locomotive Department, Stoke-upon-Trent.
1867. Bell, George, Soho Iron Works, Bolton.
1858. Bell, Isaac Lowthian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne.
1865. Bell, John, Addison Villa, Timperley, near Manchester.
1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.
1868. Belliss, George Edward, Agricultural Engine Works, Broad Street, Birmingham.
1854. Bennett, Peter Duckworth, Spon Lane Iron Foundry, Westbromwich.
1865. Benson, George Henry, Stalybridge.
1867. Berkley, George, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1867. Bernhardt, George, Stand Lane, Radcliffe, near Manchester.
1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.

1866. Bevis, Restel Ratsey, Birkenhead Iron Works, Birkenhead.
1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.
1863. Birckel, John James, Gorton Foundry, Manchester.
1866. Birkbeck, John Addison, Sheepbridge Iron Works, Chesterfield.
1847. Birley, Henry, Haigh Foundry, near Wigan.
1856. Blackburn, Isaac, Witton Park Iron Works, Darlington.
1865. Bladen, Charles, Provan Mill House, Springburn, near Glasgow.
1862. Blake, Henry Wollaston, Messrs. James Watt and Co., 18 London Street, London, E.C.
1867. Bleckly, John James, Bewsey Iron Works, Warrington.
1869. Bloomer, Benjamin Giles, Pelsall Coal and Iron Works, near Walsall.
1862. Blyth, Alfred, Steam Engine Works, Fore Street, Limehouse, London, E.
1863. Boeddinghaus, Julius, Messrs. Heinrich Boeddinghaus and Sons, Elberfeld, Prussia.
1869. Borrie, John, Cleveland Iron Works, Middlesbrough.
1862. Bouch, Thomas, 78 George Street, Edinburgh.
1858. Bouch, William, Shildon Engine Works, Darlington.
1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester. (*Life Member.*)
1862. Boyd, Nelson, Belfast Foundry, Donegal Street, Belfast.
1869. Boyd, William, Spring Gardens Engine Works, Newcastle-on-Tyne.
1854. Bragge, William, Atlas Steel and Iron Works, Sheffield.
1854. Bramwell, Frederick Joseph, 37 Great George Street, Westminster, S.W.
1868. Breeden, Joseph, 156 Cheapside, Birmingham.
1848. Broad, Robert, Horseley Iron Works, near Tipton.
1865. Brock, Walter, Vulcan Foundry, Glasgow.
1852. Brogden, Henry, Sale, near Manchester. (*Life Member.*)
1866. Brown, Andrew Betts, 80 Cannon Street, London, E.C.
1866. Brown, Charles James, St. James's Chambers, South King Street, Manchester.
1865. Brown, George, Rotherham Iron Works, Rotherham.
1863. Brown, Henry, Metropolitan Carriage and Wagon Co., Saltley Works, Birmingham.
1847. Brown, James, Jun., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1850. Brown, Sir John, Atlas Steel and Iron Works, Sheffield.
1853. Brown, Ralph, Patent Shaft Works, Wednesbury.
1869. Browne, Benjamin Chapman, Stouts Hill, Dursley.
1869. Browne, Walter Raleigh, Cookley Iron Works, near Kiddorminster.

1867. Bruce, William Duff, Executive Engineer, Presidency Division, Calcutta, India.
1865. Bryant, Frederick William, Blackfriars Bridge Works, Chatham Place, London, E.C.
1866. Bryham, William, Rose Bridge and Douglas Bank Collieries, near Wigan.
1868. Buckton, George, Well House Foundry, Meadow Road, Leeds.
1858. Burn, Henry, Midland Railway, Locomotive Department, Derby.
1856. Butler, Ambrose Edmund, Kirkstall Forge, near Leeds.
1859. Butler, John, Stanningley Iron Works, near Leeds.
1859. Butler, John Octavius, Kirkstall Forge, near Leeds.

1857. Cabry, Joseph, Resident Engineer, Blyth and Tyne Railway, Newcastle-on-Tyne.
1847. Cabry, Thomas, North Eastern Railway, York.
1847. Cammell, Charles, Cyclops Steel and Iron Works, Sheffield.
1867. Campbell, Daniel, 10 John Street, Adelphi, London, W.C.
1864. Campbell, David, 20 Castle Street, Liverpool.
1864. Campbell, James, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1869. Campbell, James, Hunslet Engine Works, Leeds.
1860. Cannell, Fleetwood James, Atlas Steel and Iron Works, Sheffield.
1860. Carbutt, Edward Hamer, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1865. Carlton, Samuel, Great Western Railway, Locomotive Department, Swindon.
1869. Carpmael, Frederick, 39 Manor Road, Lewisham Road, London, S.E.
1866. Carpmael, William, 24 Southampton Buildings, London, W.C.
1868. Carrington, Thomas, Jun., Mining Engineer, Kiveton Park Colliery, near Sheffield.
1864. Carrington, William Thomas, 10 Park Street, Westminster, S.W.
1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.
1869. Caspersen, Hans William, Engineer, Danish Government Railway Service, 11 Elswick Lane, Newcastle-on-Tyne.
1869. Chadwick, John, Junction Foundry, Watson Street, Peter Street, Manchester.
1866. Chapman, Henry, 41 Boulevard Malesherbes, Paris.
1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton.
1869. Checkley, Thomas, Mining Engineer, Lichfield Street, Walsall.
1857. Chrimes, Richard, Brass Works, Rotherham.
1869. Clapham, Robert Calvert, Walker Alkali Works, Newcastle-on-Tyne.
1866. Claridge, Thomas, Phœnix Foundry, near Bilston.
1859. Clark, George, Monkwearmouth Engine Works, Sunderland.

1867. Clark, George, Jun., Monkwearmouth Engine Works, Sunderland.
1862. Clark, James, Wellington Foundry, Leeds.
1869. Clark, Thomas, Ironfoundry, Low Elswick, Newcastle-on-Tyne.
1867. Clark, William, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1869. Clark, William, Mining Engineer, Tibshelf Collieries, near Alfreton.
1865. Clarke, John, Railway Foundry, Jack Lane, Leeds.
1869. Clarke, William, Victoria Works, Gateshead.
1859. Clay, William, Birkenhead Forge Iron Works, Beaufort Road, Birkenhead.
1863. Clayton, Robert, Soho Foundry, Preston.
1869. Clerk, Francis North, Mitre Galvanising Works, Wolverhampton.
1866. Cleworth, Charles, Assistant Locomotive Superintendent, East Indian Railway, Jumalpore, India.
1867. Cliff, Joseph, Union Foundry, Bradford, Yorkshire.
1847. Clift, John Edward, Prospect Hill, Redditch.
1860. Clunes, Thomas, Worcester Engine Works, Worcester.
1858. Cochrane, Charles, Woodside Iron Works, near Dudley.
1860. Cochrane, Henry, Ormesby Iron Works, Middlesbrough.
1854. Cochrane, John, Woodside Iron Works, near Dudley.
1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.
1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne.
1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.
1864. Coddington, William, Ordnance Cotton Mill, Blackburn.
1847. Coke, Richard George, Mining Engineer, Chesterfield.
1867. Coke, William Langton, 11 Great Queen Street, Westminster, S.W.
1864. Colburn, Zerah, 7 Gloucester Road, Regent's Park, London, N.W.
1853. Cooper, Samuel Thomas, Leeds Iron Works, Leeds.
1860. Cope, James, Mining Engineer, Pensnett, near Dudley.
1865. Corlett, Henry Lee, Great Southern and Western Railway, Carriage Department, Dublin.
1848. Corry, Edward, 8 New Broad Street, London, E.C.
1868. Coulson, William, Mining Engineer, Shamrock House, Durham.
1864. Cowans, John, St. Nicholas and Woodbank Iron Works, Carlisle.
1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.
1862. Cox, Samuel H. F., Board of Health Office, Brynmawr, Breconshire.
1847. Crampton, Thomas Russell, 12 Great George Street, Westminster, S.W.
1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.
1865. Cross, James, St. Helen's Locomotive Works, St. Helen's.
1869. Crossley, Louis J., Dean Clough Carpet Mills, Halifax.
1863. Crow, George, Messrs. R. Stephenson and Co., Newcastle-on-Tyne.
1864. Crowe, Edward, Tees Side Iron Works, Middlesbrough.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's.
1869. Daglish, John, Mining Engineer, Tynemouth, near North Shields.
1866. Daniel, Edward Freer, Castle Foundry, Caerphilly, near Cardiff.
1866. Daniel, William, 11 Blenheim Square, Leeds.
1865. Darby, Abraham, Ebbw Vale Iron Works, near Beaufort, Monmouthshire.
1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.
1865. Davidson, James, Royal Arsenal, Laboratory Department, Woolwich, S.E.
1868. Davis, Henry Wheeler, Resident Engineer, Great Eastern Railway, Stratford, London, E.
1863. Davy, Alfred, Park Iron Works, Sheffield.
1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1860. Dawes, William Henry, Bromford Iron Works, Westbromwich.
1861. Dawson, Benjamin, South Hetton, near Fence Houses.
1869. Day, St. John Vincent, 166 Buchanan Street, Glasgow.
1868. Dean, William, Great Western Railway, Locomotive Department, Swindon.
1866. Death, Ephraim, Albert Works, Leicester.
1857. De Bergue, Charles, Strangeways Iron Works, Manchester.
1858. Dees, James, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1868. Derham, John J., Brookside, near Blackburn.
1864. Dewhurst, John, 157 York Street, Hulme, Manchester.
1865. Dircks, Henry, 48 Charing Cross, London, S.W. (*Life Member.*)
1859. Dixon, John, Railway Foundry, Bradford, Yorkshire.
1865. Dobson, Benjamin, Messrs. Dobson and Barlow, Kay Street Works, Bolton.
1868. Dodman, Alfred, St. James's Works, Lynn.
1865. Douglas, Charles P., Consett Iron Works, near Blackhill, County Durham.
1857. Douglas, George K., Messrs. R. Stephenson and Co., Newcastle-on-Tyne.
1857. Dove, George, St. Nicholas and Woodbank Iron Works, Carlisle.
1866. Downey, Alfred C., Ormesby Iron Works, Middlesbrough.
1847. Dübs, Henry, Glasgow Locomotive Works, Glasgow.
1857. Dunlop, John Macmillan, Holehird, Windermere.
1854. Dunn, Thomas, 52 Withington Street, Pendleton, Manchester.
1864. Dunn, Thomas Edward, care of Messrs. Bird and Co., Allahabad, India: (or care of R. Dunn, Howick, Bilton, Northumberland.)
1861. Dutton, Charles, Sams Lane, Westbromwich.
1860. Dyson, George, Saltburn-by-the-Sea, Yorkshire.
1865. Dyson, Robert, Phœnix Wheel Tyre and Axle Works, Rotherham.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.
1859. Eassie, Peter Boyd, Railway Saw Mills, Gloucester.
1858. Easton, Edward, Grove Works, Southwark Street, London, S.E.

1867. Easton, James, Mining Engineer, Nest House, Gateshead.
1856. Eastwood, James, Railway Iron Works, Derby.
1868. Eddison, Robert William, Steam Plough and Locomotive Works, Leeds.
1866. Elce, John, Phœnix Iron Works, Jersey Street, Manchester.
1859. Elliot, George, M.P., Houghton-le-Spring, near Fence Houses.
1869. Elliott, Henry Worton, Metal Sheathing Works, Coleshill Street, Birmingham.
1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.
1860. Elwell, Thomas, Messrs. Varrall Elwell & Poulot, 9 Avenue Trudaine, Paris.
1853. England, George, Hatcham Iron Works, London, S.E.
1861. Esson, William, Engineer, Cheltenham Gas Works, Cheltenham.
1857. Evans, John Campbell, care of George W. Evans, 5 Wright Street, Hull.
1864. Everitt, William Edward, Kingston Metal Works, Adderley Street, Birmingham.
1865. Evers, Frank, Cradley Iron Works, near Stourbridge.
1869. Eyth, Max, Steam Plough and Locomotive Works, Leeds.

1869. Faija, Henry, Railway Foundry, Stoke-upon-Trent.
1868. Fairbairn, Sir Andrew, Wellington Foundry, Leeds.
1869. Fairless, John, Forth Banks Engine Works, Newcastle-on-Tyne.
1857. Fairlie, Robert Francis, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1867. Fardon, Thomas, Linslade Iron Works, Leighton Buzzard.
1865. Faviell, Samuel Clough, Clarence Iron Works, Leeds.
1866. Fenby, Joseph Beverley, 61 Pershore Road, Edgbaston, Birmingham.
1854. Fernie, John, 3 Moorland Terrace, Leeds.
1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.
1867. Field, Edward, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
1861. Field, Joshua, 110 Westminster Bridge Road, Lambeth, London, S.E.
1865. Filliter, Edward, Resident Engineer, Leeds Water Works, 16 East Parade, Leeds.
1868. Firth, Arthur, Leeds Iron Works, Leeds.
1868. Firth, Samuel, 14 Springfield Mount, Leeds.
1864. Fleet, Thomas, Crown Boiler Works, Westbromwich.
1861. Fleetwood, Daniel Joseph, 58 Broad Street, Birmingham.
1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.
1858. Fletcher, Henry Allason, Lowca Engine Works, Whitehaven. (*Life Member.*)
1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.

1866. Fletcher, James, Jun., Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.
1867. Fletcher, Lavington Evans, Association for the Prevention of Steam Boiler Explosions, 41 Corporation Street, Manchester.
1859. Fogg, Robert, 17 Park Street, Westminster, S.W.
1861. Forster, Edward, Spon Lane Glass Works, near Birmingham.
1869. Forster, George Baker, Backworth, Newcastle-on-Tyne.
1868. Forster, John, Messrs. Westray and Forster, Barrow-in-Furness, Lancashire.
1849. Forsyth, John C., North Staffordshire Railway, Stoke-upon-Trent.
1861. Foster, Sampson Lloyd, Old Park Hall, Walsall.
1847. Fothergill, Benjamin, 139 Cannon Street, London, E.C.
1866. Fowler, George, Hucknall Torkard Collieries, near Nottingham.
1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.
1847. Fox, Sir Charles, 8 New Street, Spring Gardens, London, S.W.
1866. Fox, Charles Douglas, 8 New Street, Spring Gardens, London, S.W.
1859. Fraser, John, 18 York Place, Leeds.
1866. Fraser, John Simpson, Carriage and Wagon Superintendent, Great Western Railway, Paddington, London, W.
1856. Freeman, Joseph, 98 Cannon Street, London, E.C.
1864. Frost, Thomas, Wadsley Bridge Iron and Steel Works, near Sheffield.
1852. Froude, William, Elmsleigh, Paignton, South Devon.
1866. Fry, Albert, Bristol Wagon Works, Temple Gate, Bristol.

1866. Galloway, Charles John, Knott Mill Iron Works, Manchester.
1862. Galton, Capt. Douglas, R.E., War Office, Pall Mall, London, S.W.
1847. Garland, William S., Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1867. Gauntlett, William Henry, Middlesbrough.
1848. Gibbons, Benjamin, The Leasowes, near Birmingham.
1856. Gilkes, Edgar, Tees Engine Works, Middlesbrough.
1869. Gillies, Malcolm, Great Eastern Railway, Locomotive Department, Stratford, London, E.
1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.
1862. Godfrey, Samuel, Messrs. Bolckow and Vaughan's Iron Works, Middlesbrough.
1867. Gooch, William Frederick, Vulcan Foundry, Warrington.
1869. Goodeve, Thomas Minchin, Goldsmith Buildings, Temple, London, E.C.
1865. Göransson, Göran Fredrick, Steel Works, Gefle and Hägbo, Sweden.
1865. Gray, John McFarlane, Board of Trade Steam Ship Surveyor, Custom House, Dublin.
1861. Green, Edward, Jun., Phœnix Works, Wakefield.

1867. Greenwell, George Clementson, Mining Engineer, Poynton, near Stockport.
1858. Greenwood, Thomas, Albion Works, Armley Road, Leeds.
1857. Gregory, John, 57 Millbank Street, Westminster, S.W.
1865. Greig, David, Steam Plough and Locomotive Works, Leeds.
1866. Grice, Edwin James, Stour Valley Works, Spon Lane, Westbromwich.
1860. Grice, Frederic Groom, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.
1868. Grierson, Henry Houldsworth, St. George's Iron Works, Hulme, Manchester.
1866. Gurden, Charles Frederick, Superintendent Engineer, Brazil and River Plate Steam Boat Co., 43 Canning Street, Birkenhead.

1863. Hackney, William, 3 Great George Street, Westminster, S.W.
1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.
1863. Hall, Joseph, Gratz Iron Works, Gratz, Styria, Austria.
1869. Hambling, Thomas Crump, 7 Westminster Chambers, Victoria Street, Westminster, S.W.
1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1858. Harding, John, Beeston Manor Iron Works, Leeds.
1869. Harfield, William Horatio, 28 Cornhill, London, E.C.
1859. Harman, Henry William, Canal Street Works, Manchester.
1856. Harrison, George, Canada Works, Birkenhead.
1858. Harrison, Thomas Elliot, 1 Westminster Chambers, Victoria Street, Westminster, S.W.
1865. Harrison, William, Bank Foundry, Blackburn.
1865. Harrison, William Arthur, Cambridge Street Works, Manchester.
1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.
1857. Haughton, S. Wilfred, Greenbank, Carlow, Ireland. (*Life Member.*)
1861. Hawkins, William Bailey, 2 Suffolk Lane, Cannon Street, London, E.C.
1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.
1848. Hawthorn, William, Messrs. Hawthorn and Co., Newcastle-on-Tyne.
1862. Haynes, Thomas John, Calpe Foundry, North Front, Gibraltar.
1869. Head, Jeremiah, Newport Rolling Mills, Middlesbrough.
1860. Head, John, Orwell Works, Ipswich.
1853. Headly, James Ind, Eagle Foundry, Mill Road, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1862. Heath, William J. W., Soane Irrigation Works, Baroon, Dehree on Soane, Grand Trunk Road, Shahabad, India: (or care of John J. Heath, 67 Great Charles Street, Birmingham.)

1864. Heathfield, Richard, Lion Galvanising Works, Birmingham Heath, Birmingham.
1860. Heaton, George, Royal Copper Mint, Icknield Street East, Birmingham.
1868. Heaton, John, Langley Mill Steel and Iron Works, near Nottingham.
1869. Henderson, David Marr, Chief Coast-Lights Engineer for China, Imperial Maritime Customs, Shanghai, China.
1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.
1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.
1864. Hetherington, William Isaac, Vulcan Works, Pollard Street, Manchester.
1865. Hewett, Edward Edwards, Don Steel Works, Sheffield.
1866. Hickman, George Haden, Groveland Iron Works, Dudley Port, Tipton.
1864. Hide, Thomas C., Chief Engineer, H. M. Dockyard, Calcutta, India: (or care of Messrs. Holland Jacques and Co., 21 Great St. Helen's, London, E.C.)
1869. Hind, Henry, Central Works, Queen's Road, Nottingham.
1866. Hodgson, Charles, 21 Gresham Street, Old Jewry, London, E.C.
1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.
1852. Holcroft, James, Norton, near Stourbridge.
1866. Holcroft, Thomas, Bilston Foundry, Bilston.
1865. Holliday, John, Messrs. Bethell's Creosote Works, Westbromwich.
1863. Holt, Francis, Gorton Foundry, Manchester.
1867. Holt, William Lyster, 7 Great Winchester Street Buildings, London, E.C.
1867. Homer, Charles James, Mining Engineer, Chatterley Ironstone Works, Tunstall, near Stoke-upon-Trent.
1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.
1860. Hopkins, James Innes, The Poplars, Kingston-on-Thames.
1866. Hopkins, John Satchell, Tinplate Works, Granville Street, Birmingham.
1856. Hopkinson, John, London Road Iron Works, Manchester.
1867. Hopper, William, Machine Works, Moscow, Russia.
1867. Horrocks, Samuel, 51 King Street, Manchester.
1868. Horsley, Thomas, Alfreton Iron Works, Alfreton.
1858. Horsley, William, Jun., Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.
1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.
1851. Horton, Joshua, Ætna Works, Smethwick, near Birmingham.
1867. Horton, Thomas Ellwood, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.
1858. Hosking, John, Gateshead Iron Works, Gateshead.
1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.
1864. Howard, Eliot, 84 Upper Whitecross Street, London, E.C.
1860. Howard, James, M.P., Dulwich House, Sydenham Hill, London, S.E.
1867. Howard, Robert Luke, 84 Upper Whitecross Street, London, E.C.

1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.
1861. Howell, Joseph Bennett, Hartford Steel Works, Sheffield.
1866. Hoyle, William Jennings, Sir Joseph Whitworth and Co., Chorlton Street, Manchester.
1868. Hudswell, William Shillito, Railway Foundry, Jack Lane, Leeds.
1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.
1864. Hulse, William Wilson, Whalley Chambers, 88 King Street, Manchester.
1859. Hunt, James P., Corngreaves Iron Works, near Birmingham.
1856. Hunt, Thomas, Nantwich Road, Crewe.
1864. Hutchinson, Edward, Skerne Iron Works, Darlington.
1863. Hutton, Walter Stuart, Prospect Works, Hunslet Lane, Leeds.
1865. Hyde, Lt.-Colonel Henry, R.E., Master of the Mint, Calcutta, India: (or care of Rev. H. M. C. Hyde, 184 The Grove, Camberwell, London, S.E.) (*Life Member.*)

1867. Inglis, William, Soho Iron Works, Bolton.
1866. Ireland, William, 41 Beech Lane, Macclesfield.

1865. Jackson, John, Stibbington House, Wansford.
1859. Jackson, Matthew Murray, Engineer-in-Chief, Imperial Danube Steam Navigation Works, Pesth, Austria.
1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.
1860. Jackson, Samuel, Cyclops Steel and Iron Works, Sheffield.
1866. Jaeger, Herrmann Frederic, Gorton Foundry, Manchester.
1858. Jaffrey, George William, Hartlepool Iron Works, Hartlepool.
1856. James, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.E.
1868. James, John, Ebbw Vale Iron Works, near Tredegar.
1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.
1863. Jeffreys, Edward A., Low Moor Iron Works, near Bradford, Yorkshire.
1861. Jessop, Thomas, Park Steel Works, Sheffield.
1854. Jobson, John, Derwent Foundry, Derby.
1868. Jobson, Robert, Phœnix Works, Dudley.
1863. Johnson, Bryan, Flookersbrook Foundry, Chester.
1847. Johnson, James, North Staffordshire Railway, Engineer's Office, Stoke-upon-Trent.
1861. Johnson, Samuel Waite, Locomotive Superintendent, Great Eastern Railway, Stratford, London, E.
1847. Jones, Edward, The Larches, Handsworth, near Birmingham.
1857. Jones, Hodgson, 67 Victoria Street, Westminster, S.W.

1857. Kay, James Clarkson, Phœnix Foundry, Bury, Lancashire.
1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1869. Keep, Alfred, Metal Sheathing Works, Coleshill Street, Birmingham.
1867. Kellett, John, 2 Newshams Buildings, King Street, Wigan.
1857. Kendall, William, Locomotive Superintendent, Blyth and Tyne Railway, Percy Main, near Newcastle-on-Tyne.
1863. Kennan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.
1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.
1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway; 45 Finsbury Circus, London, E C.
1868. Kennedy, Thomas Stuart, Wellington Foundry, Leeds.
1868. Kerr, Peter, Thread Works, New Street, Paisley.
1866. Kershaw, John, 24 Duke Street, Westminster, S.W.
1867. Kimball, Frederick James, 35 South Third Street, Philadelphia, Pennsylvania, United States.
1865. Kirkaldy, David, Testing and Experimental Works, The Grove, Southwark Street, London, S.E.
1847. Kirtley, Matthew, Locomotive Superintendent, Midland Railway, Derby.
1864. Kirtley, William, Midland Railway, Locomotive Department, Derby.
1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.
1848. Kitson, James, Airedale Foundry, Leeds.
1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.
1868. Kitson, John Hawthorn, Airedale Foundry, Leeds.
1866. Knap, Conrad, Star Tube Works, Heneage Street, Birmingham.
1869. Koe, Stephen Lancelot, Bowling Iron Works, near Bradford, Yorkshire.
1869. Kohn, Ferdinand, 6 Robert Street, Adelphi, London, W.C.

1866. Lambert, William Blake, 3 Morden Road, Blackheath, London, S.E.
1867. Lancaster, Charles William, Gun Manufactory, 151 New Bond Street, London, W.
1863. Lancaster, John, M.P., Kirkless Hall Coal and Iron Works, near Wigan.
1860. Law, David, Phœnix Iron Works, Glasgow.
1867. Lawrence, Henry, The Grange Iron Works, Durham.
1857. Laybourn, John, Isca Foundry, Newport, Monmouthshire.
1856. Laybourn, Richard, Rhymney Iron Works, Tredegar.
1860. Lea, Henry, 35 Paradise Street, Birmingham.
1868. Lea, John, Bowling Iron Works, near Bradford, Yorkshire.
1865. Ledger, Joseph, West Cumberland Hæmatite Iron Works, Workington.
1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.
1863. Lees, Samuel, Jun., Park Bridge Iron Works, Ashton-under-Lyne.
1863. Leigh, Evan, Clarence House, Manchester.
1865. Leigh, Frederick Allen, Boston, United States.
1866. Leigh, Joseph D., Ellesmere Foundry, Patricroft, near Manchester.

1858. Leslie, Andrew, Iron Ship Building Yard, Hebburn Quay, Gateshead.
1860. Lewis, Thomas William, Abercanaid House, Merthyr Tydvil.
1864. Lindsley, George, Great Western Railway, Locomotive Department, Swindon.
1856. Linn, Alexander Grainger, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1857. Little, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1866. Little, George, Hartford Iron Works, Oldham.
1867. Livesey, James, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1867. Lloyd, Charles, 6 Westminster Chambers, Victoria Street, Westminster, S.W.
1863. Lloyd, Edward R., Albion Tube Works, Nile Street, Birmingham.
1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)
1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.
1866. Lloyd, Joseph Foster, Darlaston Green Iron and Steel Works, near Wednesbury.
1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury.
1864. Lloyd, Sampson Zachary, Old Park Iron Works, Wednesbury.
1852. Lloyd, Samuel, Old Park Iron Works, Wednesbury.
1862. Lloyd, Wilson, Moor Hall, Sutton Coldfield, near Birmingham.
1863. Loam, Matthew Hill, Engineer, Gas and Water Works, Nottingham.
1869. Lockhart, Humphrey Campbell, Birmingham Plate Glass Works, Smethwick, near Birmingham.
1856. Longridge, Robert Bewick, Steam Boiler Assurance Company, 67 King Street, Manchester.
1865. Longridge, William Smith, Alderwasley Iron Works, Ambergate, near Derby.
1866. Lord, Edward, Canal Street Works, Todmorden.
1859. Lord, Thomas Wilks, Bank Mills, Leeds.
1861. Low, George, St. Peter's Iron Works, Ipswich.
1854. Lynde, James Gascoigne, Town Hall, Manchester.
1868. Lyndon, George Frederick, Minerva Works, Fazeley Street, Birmingham.

1869. Mabbutt, Thomas, Abingdon Gun Works, Shadwell Street, Birmingham.
1864. Macfarlane, Walter, Saracen Foundry, Glasgow.
1856. Mackay, John, Mount Hermon, Drogheda.
1864. Macnab, Archibald Francis, Peninsular and Oriental Steam Navigation Co., Hong-Kong, China: (or care of P. and O. S. N. Co., 122 Leadenhall Street, London, E.C.)
1865. MacNay, William, Shildon Engine Works, Darlington.
1865. Macnee, Daniel, Brinsworth Iron and Steel Works, Rotherham.

1867. Mallet, Robert, 7 Westminster Chambers, Victoria Street, Westminster, S.W.
1859. Manning, John, Boyne Engine Works, Hunslet, Leeds.
1862. Mansell, Richard Christopher, South Eastern Railway, Carriage Department, Ashford.
1862. Mappin, Frederick Thorpe, Sheaf Works, Sheffield.
1857. March, George, Union Foundry, Dewsbury Road, Leeds.
1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1865. Marshall, Francis Carr, Jarrow Engine Works, Quayside, Newcastle-on-Tyne.
1862. Marshall, James, North Eastern Railway, Carlisle.
1859. Marshall, William Ebenezer, Sun Foundry, Dewsbury Road, Leeds.
1847. Marshall, William Prime, 81 Newhall Street, Birmingham.
1859. Marten, Edward Bindon, Engineer, Stourbridge Water Works, 56 Hagley Street, Stourbridge.
1853. Marten, Henry John, Parkfield Iron Works, near Wolverhampton.
1867. Martin, William, Messrs. W. Martin Fils et Cie., 43 Rue d'Elbeuf, Rouen, France.
1857. Martindale, Lt.-Colonel Ben Hay, R.E., Controller, Montreal, Canada.
1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.
1864. Martley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W.
1857. Masselin, Armand, 14 Rue de Lancry, Paris.
1867. Mather, William, Salford Iron Works, Manchester.
1853. Mathews, William, North Grove, Great Malvern.
1847. Matthews, William Anthony, Sheaf Works, Sheffield.
1853. Maudslay, Henry, Bystock, near Exmouth. (*Life Member.*)
1864. Maudslay, Thomas Henry, 110 Westminster Bridge Road, Lambeth, London, S.E.
1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.
1869. May, George, Mining Engineer, North Hetton and Pittington Collieries, Fence Houses.
1861. May, Robert Charles, 6 Great George Street, Westminster, S.W.
1857. May, Walter, Suffolk Works, Berkley Street, Birmingham.
1865. Maylor, John, 11 Commerce Chambers, Lord Street, Liverpool.
1859. Maylor, William, Calicut, Madras, India.
1847. McClean, John Robinson, M.P., 23 Great George Street, Westminster, S.W.
1865. McDonnell, Alexander, Locomotive Superintendent, Great Southern and Western Railway, Dublin.
1867. McEwen, James, Wordsley Foundry, Stourbridge.
1864. McEwen, Lawrence Thompson, Glaisdale Iron Works, near Yarm.

1868. McKay, Benjamin, Small Arms Factory, Small Heath, near Birmingham.
1860. McKenzie, James, Well House Foundry, Meadow Road, Leeds.
1859. McKenzie, John, Worcester Engine Works, Worcester.
1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.
1858. Meik, Thomas, Engineer to the River Wear Commissioners, Sunderland.
1857. Menelaus, William, Dowlais Iron Works, Merthyr Tydvil.
1866. Meredith, Alban, 96 Newgate Street, London, E.C.
1867. Merryweather, Richard M., 63 Long Acre, London, W.C.
1857. Metford, William Ellis, Flook House, Taunton.
1862. Miers, Francis C., Stoneleigh Lodge, Grove Road, Clapham Park, London, S.W.
1864. Miers, John William, 74 Addison Road, Kensington, London, W.
1862. Millward, John, Curzon Chambers, 27 Paradise Street, Birmingham.
1856. Mitchell, Charles, Iron Shipbuilding Yard, Low Walker, Newcastle-on-Tyne.
1861. Mitchell, Joseph, Worsbrough Dale Colliery, near Barnsley.
1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1864. Moore, Sampson, North Foundry, Cotton Street, Clarence Dock, Liverpool.
1864. Morgan, Joshua Llewelyn, Kingscombe, near Cowbridge.
1867. Morgans, Thomas, Mells Iron Works, near Frome.
1868. Morris, William, Waldridge Colliery, Chester-le-Street, near Fence Houses.
1849. Morrison, Robert, Brotton Grange, Saltburn-by-the-Sea, Yorkshire.
1865. Morton, Robert, Alliance Chambers, Borough, London, S.E.
1865. Mosse, James Robert, Mauritius Railways, Port Louis, Mauritius.
1858. Mountain, Charles George, Suffolk Works, Berkley Street, Birmingham.
1866. Muir, Andrew, Victoria Bridge Works, Salford, Manchester.
1863. Muir, William, 59 Shardeloes Road, New Cross, London, S.E.
1865. Murdock, William Mallabey, Barrow Hæmatite Steel Works, Barrow-in-Furness, Lancashire.
1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street, near Fence Houses.
1863. Musgrave, John, Jun., Globe Iron Works, Bolton.

1848. Napier, John, Vulcan Foundry, Glasgow.
1867. Napier, John D., Kilmun House, Holt Hill, Birkenhead.
1856. Napier, Robert, West Shandon, Helensburgh, near Glasgow. (*Life Member.*)
1861. Naylor, John William, Wellington Foundry, Leeds.
1858. Naylor, William, Great Indian Peninsula Railway, 3 New Broad Street, London, E.C.
1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow.

1869. Nelson, James, Bonners Field Foundry, Sunderland.
1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.
1866. Newdigate, Albert Lewis, Byrkley Lodge, near Burton-on-Trent.
1862. Newton, William Edward, 66 Chancery Lane, London, W.C.
1858. Nichol, Peter Dale, Sunderland Engine Works, South Dock, Sunderland.
1866. Norfolk, Richard, Beverley Iron and Wagon Works, Beverley.
1850. Norris, Richard Stuart, 272 Upper Parliament Street, Liverpool.
1868. Norris, William Gregory, Coalbrookdale Iron Works, near Wellington, Shropshire.
1869. North, Frederic William, Mining Engineer, Rowley Hall Colliery, Rowley Regis, near Dudley.

1868. O'Connor, Charles, Newark Foundry, Bath.
1866. Oliver, William, Victoria Foundry, Chesterfield.
1867. Olrick, Lewis, 27 Leadenhall Street, London, E.C.
1864. Ommanney, Frederick Francis, New Bridge Foundry, Adelphi Street, Salford, Manchester.
1867. Oughterson, George Blake, Messrs. W. Martin Fils et Cie., 43 Rue d'Elbeuf, Rouen, France.
1847. Owen, William, Phœnix Wheel Tyre and Axle Works, Rotherham.

1868. Paget, Arthur, Machine Works, Loughborough.
1869. Palmer, Alfred Septimus, Mining Engineer, Quayside, Newcastle-on-Tyne.
1868. Parker, Frederick, Steam Plough and Locomotive Works, Leeds.
1868. Parker, Henry, Meadow Works, Holywell, North Wales.
1869. Parker, Thomas, Mersey Wheel Works, Nottingham Road, Derby.
1865. Parkes, Alexander, Stephenson Metal Tube Works, Liverpool Street, Birmingham.
1866. Parton, Thomas, Rough Hay Iron Works, Darlaston, near Wednesbury.
1869. Peacock, Ralph, Gorton Foundry, Manchester.
1869. Peacock, Ralph, Cyclops Iron Works, Goole.
1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Calcutta, India.
1848. Pearson, John, 7 Old Hall Street, Liverpool.
1869. Pearson, William Hall, Minerva Works, 29 Islington, Birmingham.
1866. Peel, George, Jun., Soho Iron Works, Pollard Street, Manchester.
1866. Peele, Arthur John, 90 Queen Street, London, E.C.
1848. Penn, John, The Cedars, Lee, London, S.E. (*Life Member.*)
1861. Perkins, Loftus, 6 Seaford Street, Regent Square, London, W.C.
1866. Perks, John Hartley, Shrubbery Iron Works, Wolverhampton.

1856. Perring, John Shae, 104 King Street, Manchester.
1863. Perry, Thomas J., Highfields Engine Works, Bilston.
1865. Perry, William, Messrs. Samuel Perry and Sons, Wednesbury.
1860. Peyton, Edward, Bordesley Works, Birmingham.
1869. Pickersgill, Thomas, Mining Engineer, Waterloo Main Colliery, Leeds.
1867. Pidgeon, Daniel, Britannia Iron Works, Banbury.
1856. Piggott, George, King's Heath, Birmingham.
1854. Pilkington, Richard, Summerdale, Trinity Road, Birchfield, Birmingham.
1859. Pitts, Joseph, Stanningley Iron Works, near Leeds.
1859. Platt, John, M.P., Hartford Iron Works, Oldham.
1867. Platt, Samuel Radcliffe, Hartford Iron Works, Oldham.
1862. Player, John, 3904 Walnut Street, Philadelphia, Pennsylvania, United States: (or care of William J. Player, Longford Court, Neath.)
1869. Player, John, Jun., Clydach Foundry, near Swansea.
1866. Plum, Thomas Edward Day, Atlas Works, Manchester.
1861. Plum, Thomas William, Old Park Iron Works, near Shiffnal.
1860. Ponsonby, Edward Vincent, Parker Place, Broomhill, Sheffield.
1866. Porter, Charles Talbot, Allen Engine Works, Fourth Avenue, Harlem, New York, United States.
1861. Porter, Robert, 172 Fenchurch Street, London, E.C.
1869. Potter, William Anbone, Mining Engineer, Cramlington House, Cramlington, Northumberland.
1864. Potts, Benjamin Langford Foster, 200 Camberwell Grove, London, S.E.
1851. Potts, John Thorpe, 200 Camberwell Grove, London, S.E.
1867. Powell, William, Harbour Works, Port Erin, Isle of Man.
1867. Pratchitt, John, Denton Iron Works, Carlisle.
1865. Pratchitt, William, Denton Iron Works, Carlisle.
1856. Preston, Francis, Ancoats Bridge Works, Ardwick, Manchester.
1866. Price, John, Chief Surveyor, Underwriters' Registry for Iron Vessels, 37 West Sunniside, Sunderland.
1869. Purves, John, Superintending Engineer, Liverpool New York and Philadelphia Steam Ship Co., Water Street, Liverpool.
1866. Putnam, William, Darlington Forge, Darlington.

1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.
1862. Rake, Alfred Stansfield, Bank Buildings, Newcastle-on-Tyne.
1864. Ramage, Robert, Locomotive Superintendent, Midland Great Western Railway, Dublin.
1847. Ramsbottom, John, Locomotive Superintendent, London and North Western Railway, Crewe.
1866. Ramsden, James, Abbot's Wood, Barrow-in-Furness, Lancashire.

1860. Ransome, Allen, Jun., Messrs. Worssam and Co., King's Road, Chelsea, London, S.W.
1869. Ransome, Robert Charles, Orwell Works, Ipswich.
1862. Ransome, Robert James, Orwell Works, Ipswich.
1867. Ratcliff, Daniel Rowlinson, Phœnix Safe Works, Liverpool.
1867. Ratliffe, George, London and North Western Railway, Locomotive Department, Crewe.
1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.
1859. Rennie, George Banks, 20 Lowndes Street, Lowndes Square, London, S.W.
1862. Reynolds, Edward, Don Steel Works, Sheffield.
1866. Richards, Edward Windsor, Ebbw Vale Iron Works, near Beaufort, Monmouthshire.
1865. Richards, Job, Parkgate Iron Works, Rotherham.
1856. Richards, Josiah, Abersychan Iron Works, Pontypool.
1863. Richardson, Edward, Lyttelton and Christchurch Railway, Christchurch, New Zealand.
1865. Richardson, John, Methley, near Leeds.
1858. Richardson, Thomas, Hartlepool Iron Works, Hartlepool.
1859. Richardson, William, Hartford Iron Works, Oldham.
1863. Rigby, Samuel, Cock Hedge Mill, Warrington.
1848. Robertson, Henry, Great Western Railway, Shrewsbury.
1865. Robey, Robert, Perseverance Iron Works, Lincoln.
1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1865. Robinson, John, Railway Works, Rochdale.
1866. Robson, Thomas, Mining Engineer, Lumley Colliery, Fence Houses.
1868. Rogers, William, Resident Engineer, Port Wakefield and Hoyles Plains Railway, Port Wakefield, near Adelaide, South Australia.
1853. Ronayne, Joseph P., 4 Harbour Hill, Queenstown, Ireland.
1867. Rose, Henry Fullwood, Albert Iron Works, Moxley, near Wednesbury.
1866. Rose, Thomas, Bradley Iron Works, near Bilston.
1867. Rose, Thomas, Machine Works, 37 Victoria Street, Manchester.
1869. Rose, William Napoleon, Albert Iron Works, Moxley, near Wednesbury.
1866. Rosthorn, Joseph De, Messrs. Rosthorn Brothers, Vienna.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Boston.
1857. Routledge, William, New Bridge Foundry, Adelphi Street, Salford, Manchester.
1860. Rumble, Thomas William, 6A Victoria Street, Westminster, S.W. (*Life Member.*)
1847. Russell, John Scott, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1867. Ruston, Joseph, Sheaf Iron Works, Lincoln.
1866. Ryland, Frederick, Messrs. Kenrick's Works, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, Yorkshire Engine Co., Meadow Hall Works, near Sheffield.
1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1868. Sacré, Edward Antoine, 26 Parliament Street, Westminster, S.W.
1867. Sadoine, Eugène, Société Cockerill, Seraing, Belgium.
1864. Said, Colonel M., Bey, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)
1859. Salt, George, Saltaire, near Bradford, Yorkshire.
1864. Samuda, Joseph D'Aguilar, M.P., Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.
1848. Samuel, James, 26 Great George Street, Westminster, S.W.
1857. Samuelson, Alexander, 27 Cornhill, London, E.C.
1865. Samuelson, Bernhard, M.P., Britannia Iron Works, Banbury.
1857. Samuelson, Martin, Engine Works, Neptune Street, Hull.
1865. Sandberg, Christer Peter, Engineer, Swedish Government Railway Service, Stockholm, Sweden: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)
1861. Sanderson, George Grant, Tudhoe Iron Works, near Ferryhill.
1864. Sanderson, John, Waskerley Park, near Darlington.
1869. Scarlett, James, 14 St. Ann's Square, Manchester.
1869. Schanschieff, Alexandre, Engineer, Russian Imperial Navy; Commercial Road, Newport, Monmouthshire.
1866. Scholtze, Aleksander, Messrs. Scholtze Brothers, Engineers and Boiler Makers, Warsaw, Poland.
1865. Scott, Edward, 10 Tib Lane, Cross Street, Manchester.
1868. Scott, George Lamb, 6 Orleans Chambers, 4 St. Mary's Gate, Manchester.
1861. Scott, Walter Henry, Locomotive and Carriage Superintendent, Mauritius Railways, Port Louis, Mauritius: (or care of James Murray, 16 Brunswick Street, Barnsbury Road, London, N.)
1868. Scriven, Charles, Leeds Old Foundry, Marsh Lane, Leeds.
1864. Seddon, John, Wallgate, Wigan.
1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.
1867. Selby, Millin, Teakova Cotton Mill, near Ivanova, Vladimir, Russia: (or care of Millin Selby, Sen., Atherton Hall, Leigh, near Manchester.)
1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.
1850. Shanks, Andrew, 6 Robert Street, Adelphi, London, W.C.
1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.

1867. Sharpe, Charles James, 17B Great George Street, Westminster, S.W.
1862. Sharpe, William John, 1 Victoria Street, Westminster, S.W.
1869. Sharrock, Samuel, Windsor Iron Works, Spekeland Street, Edge Hill, Liverpool.
1864. Shaw, Duncan, Mining Engineer, Cordova, Spain.
1856. Shelley, Charles Percy Bysshe, 113 Victoria Street, Westminster, S.W.
1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.
1859. Shuttleworth, Joseph, Stamp End Iron Works, Lincoln.
1851. Siemens, Charles William, 3 Great George Street, Westminster, S.W.
1862. Silvester, John, Messrs. George Salter and Co., Spring Balance Works, Westbromwich.
1847. Sinclair, Robert, Great Eastern Railway, Stratford, London, E.
1857. Sinclair, Robert Cooper, Hartshill, near Atherstone.
1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.
1853. Slaughter, Edward, Avonside Engine Works, Bristol.
1866. Smethurst, Joseph, Guide Bridge Iron Works, Audenshaw, near Manchester.
1866. Smith, Edward Fisher, Coneygre Iron Works, Dudley Port, Dudley.
1866. Smith, Fereday, Bridgewater Offices, Manchester.
1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.
1860. Smith, John, Brass Foundry, Traffic Street, Derby.
1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow-in-Furness, Lancashire.
1859. Smith, Matthew, Caledonia Wire Mills, Halifax.
1857. Smith, William, 19 Salisbury Street, Adelphi, London, W.C.
1866. Smith, William, Eglinton Engine Works, Glasgow.
1863. Smith, William Ford, Gresley Iron Works, Ordsal Lane, Salford, Manchester.
1857. Snowdon, Thomas, 147 High Street, Stockton-on-Tees.
1859. Sokoloff, Colonel Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)
1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Messrs. Tottie and Sons, 2 Alderman's Walk, Bishopsgate Street, London, E.C.)
1865. Sparrow, Arthur, Lane End Iron Works, Longton, near Stoke-upon-Trent.
1865. Sparrow, William Mander, Osier Bed Iron Works, Wolverhampton.
1866. Spencer, Eli, Hartford Iron Works, Oldham.
1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne.
1853. Spencer, Thomas, Clough Hall Iron Works, Kidsgrove, near Stoke-upon-Trent.
1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.

1864. Spittle, Thomas, Cambrian Iron Foundry, Newport, Monmouthshire.
1862. Stableford, William, Oldbury Carriage Works, near Birmingham.
1869. Stabler, James, 75 Upper Ground Street, Blackfriars Road, London, S.E.
1869. Stenson, Foster, Burton Iron Works, Burton-on-Trent.
1868. Stenson, William Towndrow, Whitwick Colliery, Coalville, near Leicester.
1866. Stephens, John Classon, Blackhall Place Iron Works, Dublin.
1868. Stephenson, George Robert, 24 Great George Street, Westminster, S.W.
1866. Stevenson, John, Acklam Iron Works, Middlesbrough.
1867. Stevenson, Robert, Mining Engineer, Clay Cross, near Chesterfield.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester.
1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.
1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.
1864. Stokes, James Folliott, Punjab Club, Lahore, India: (or care of Charles P. B. Shelley, 113 Victoria Street, Westminster, S.W.)
1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.
1862. Strong, Joseph F., Resident Engineer, East Indian Railway, Cawnpore, India.
1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.
1861. Sumner, William, 2 Brazenose Street, Manchester.
1860. Swindell, James Evers, Parkhead Iron Works, Dudley.
1864. Swindell, James Swindell Evers, Cradley Iron Works, near Brierley Hill.
1867. Swingler, Henry, Victoria Foundry, Litchurch, near Derby.
1859. Swingler, Thomas, Victoria Foundry, Litchurch, near Derby.

1861. Tangye, James, Cornwall Works, Clement Street, Birmingham.
1859. Tannett, Thomas, Victoria Foundry, Leeds.
1861. Taylor, George, Clarence Iron Works, Leeds.
1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.
1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1867. Taylor, Joseph, Derwent Foundry, 99 Constitution Hill, Birmingham.
1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.
1868. Taylor, Samuel, Clarence Iron Works, Leeds.
1864. Tennant, Charles, The Glen, Innerleithen, near Edinburgh. (*Life Member.*)
1867. Thomas, Joseph Lee, 7 Holland Terrace, Kensington, London, W.

1864. Thomas, Thomas, Llynvi Vale Iron Works, near Bridgend.
1857. Thompson, Robert, Haigh Foundry, near Wigan.
1862. Thompson, William, Spring Gardens Engine Works, Newcastle-on-Tyne.
1868. Thomson, John, Engine Works, 36 Finnieston Street, Glasgow.
1865. Thorn, Alexander, Steam Saw Mills, Chelsea, London, S.W.
1868. Thornewill, Robert, Burton Iron Works, Burton-on-Trent.
1861. Thwaites, Robinson, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1865. Tickle, John, Providence Engine Works, Westbromwich.
1862. Tijou, William, 27 Great George Street, Westminster, S.W.
1862. Tolmé, Julian Horn, 1 Victoria Street, Westminster, S.W.
1857. Tomlinson, Joseph, Jun., Cardiff.
1867. Tonks, Edmund, Brass Works, Moseley Street, Birmingham.
1865. Toomey, Edward, Royal Phœnix Iron Works, Dublin.
1856. Tosh, George, North Lincolnshire Iron Works, Frodingham, near Brigg.
1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.
1863. Townsend, William, West Orchard, Coventry.
1865. Trow, John James, Timber Works, Bilston Road, Wednesbury.
1862. Troward, Charles, 8 Sussex Terrace, Camden Town, London, N.W.
1866. Turner, Frederick, St. Peter's Iron Works, Ipswich.
1867. Turner, Henry, Hazel House, Balaam Street, Plaistow, London, E.
1867. Tweddell, Ralph Hart, Engine Works, Richmond Street, Sunderland.
1856. Tyler, Captain Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1862. Upward, Alfred, Engineer, Chartered Gas Works, 146 Goswell Street, London, E.C.
1865. Usher, George Moon, Beverley Iron and Wagon Works, Beverley.

1868. Vallance, Frederick Bevoley, Alicel Engine Works, Bridge Street, Greenwich, S.E.
1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.
1856. Vernon, John, Regent Road, Sandon Dock, Liverpool.
1865. Vickers, Albert, Don Steel Works, Sheffield.
1861. Vickers, Thomas Edward, Don Steel Works, Sheffield.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.
1856. Waddington, Thomas, Heaton Lodge, Wortley, near Leeds.
1865. Wainwright, William, Great Western Railway, Locomotive Department, Worcester.
1863. Wakefield, John, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.

1867. Walker, Benjamin, Goodman Street Works, Hunslet, Leeds.
1864. Walker, Bernard Peard, Junction Cut Nail Works, Wolverhampton.
1867. Walker, Charles Clement, Midland Iron Works, Donnington, near Newport, Shropshire.
1847. Walker, Thomas, Patent Shaft Works, Wednesbury.
1863. Walker, William Hugill, Wicker Iron Works, Sheffield.
1863. Wallace, William, Superintending Engineer, Montreal Ocean Steam Ship Works, Liverpool.
1865. Waller, George Arthur, Messrs. Guinness, James' Gate, Dublin.
1868. Wallis, Herbert, Midland Railway, Locomotive Department, Bradford, Yorkshire.
1865. Walpole, Thomas, Windsor Lodge, Monkstown, near Dublin.
1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Glover Street, Birmingham.
1856. Wardle, Charles Wetherell, Boyne Engine Works, Hunslet, Leeds.
1852. Warham, John R., Burton Iron Works, Burton-on-Trent.
1867. Watkin, William John Laverick, Mining Engineer, Pemberton Colliery, near Wigan.
1862. Watkins, Richard, Canal Iron Works, Poplar, London, E.
1866. Watson, Robert, Engineer, Black Boy Collieries, Bishop Auckland.
1862. Webb, Francis William, Bolton Iron and Steel Works, Bolton.
1862. Webb, Henry Arthur, Bretwell Hall Iron Works, near Stourbridge.
1860. Weild, William, Tipping Street, Ardwick, Manchester.
1862. Wells, Charles, Moxley Iron Works, near Bilston.
1862. Westmacott, Percy G. B., Elswick Engine Works, Newcastle-on-Tyne.
1867. Weston, Thomas Aldridge, care of William T. Watts, 78 Parade, Birmingham.
1867. Wheatley, Thomas, Locomotive Superintendent, North British Railway, Edinburgh.
1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston.
1864. White, Isaiah, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain: (or care of Isaac White, Pontardulais, Llanelly.)
1868. Whitehead, Peter Ormerod, Ilex Cotton Mill, Rawtenstall, near Manchester.
1862. Whitehead, William, Don Steel Works, Sheffield.
1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.
1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.
1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.
1866. Whitwell, Thomas, Thornaby Iron Works, Stockton-on-Tees.
1847. Whitworth, Sir Joseph, Bart., The Firs, Fallowfield, Manchester.
1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford, Yorkshire.

1863. Wicksteed, Thomas, 8 Torquay Terrace, Headingley, near Leeds. (*Life Member.*)
1868. Wigham, John Richardson, Stafford Works, Stafford Street, Dublin.
1868. Wigram, Reginald, Steam Plough and Locomotive Works, Leeds.
1867. Wilkes, Gilbert, Tube Works, Bordesley Mills, Birmingham.
1867. Wilkes, John, Tube Works, Bordesley Mills, Birmingham.
1868. Wilkieson, Lt.-Colonel Charles Vaughan, R.E., care of Messrs. Richardson and Co., 13 Pall Mall, London, S.W.
1865. Williams, Edward, Messrs. Bolckow and Vaughan's Iron Works, Middlesbrough.
1847. Williams, Richard, Patent Shaft Works, Wednesbury.
1859. Williams, Richard Price, 37 Great George Street, Westminster, S.W.
1869. Williams, Walter, Wednesbury Oak Iron Works, Tipton.
1856. Wilson, Edward, 9 Dean's Yard, Westminster, S.W.
1859. Wilson, George, Cyclops Steel and Iron Works, Sheffield.
1867. Wilson, Henry, Brass Works, Stockton-on-Tees.
1865. Wilson, James Edwards, Engineer, Indian Branch Railways, Cawnpore, India.
1863. Wilson, John Charles, East India House, 5 Lime Street, London, E.C.
1857. Wilson, Robert, Bridgewater Foundry, Patricroft, near Manchester.
1860. Wilson, William, 4 Victoria Street, Westminster, S.W.
1865. Winby, Clifford Etches, Atlas Iron Works, Cardiff.
1867. Winby, Frederick Charles, Atlas Iron Works, Cardiff.
1862. Winby, William Edward, Old Park Iron Works, Wednesbury.
1859. Winter, Thomas Bradbury, 28 Moorgate Street, London, E.C.
1868. Wood, Lindsay, Mining Engineer, Hetton Colliery, Hetton, near Fence Houses.
1869. Wood, Thomas James Vickers, Springfield Mill, Cleckheaton, near Normanton.
1865. Woodall, Solomon, Windmill End Boiler Works, near Dudley.
1848. Woodhouse, Henry, London and North Western Railway, Stafford.
1851. Woodhouse, John Thomas, Mining Engineer, Midland Road, Derby.
1858. Woods, Hamilton, Liver Foundry, Ordsal Lane, Salford, Manchester.
1860. Worthington, Samuel Barton, Engineer, London and North Western Railway, Manchester.
1866. Wray, William, Ship Building Yard, Burton Stather, near Brigg.
1866. Wren, Henry, London Road Iron Works, Manchester.
1867. Wright, John Turner, Universe Rope Works, Garrison Street, Birmingham.
1859. Wright, Joseph, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.
1860. Wright, Joseph, Neptune Forge, Tipton Green, Dudley.
1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.

1863. Wright, Peter, Railway Wheel Vice and Anchor Works, Dudley.
1865. Wyllie, Andrew, Vauxhall Foundry, Liverpool.

1861. Yule, William, 102 New Canal, St. Petersburg.

## HONORARY LIFE MEMBERS.

1865. Downing, Samuel, LL.D., Trinity College, Dublin.
1847. Fairbairn, Sir William, Bart., The Polygon, Ardwick, Manchester.
1867. Morin, General Arthur, Director, Conservatoire Impérial des Arts et Métiers, Paris.
1867. Tresca, Henri, Engineer Sub-Director, Conservatoire Impérial des Arts et Métiers, Paris.

## ASSOCIATES.

1865. Barker, Frederick, Leeds Iron Works, Leeds.
1868. Beale, Montague, 1 Great Winchester Street Buildings, London, E.C.
1867. Blinkhorn, William, London and Manchester Plate Glass Works, Sutton, St. Helen's.
1866. Chadwick, William, Monkbridge Iron Works, Leeds.
1848. Crosby, Samuel, Tenby House, Victoria Road, Aston, Birmingham.
1866. Crossley, John, British Plate Glass Works, Ravenhead, near St. Helen's.
1867. Dewhurst, John Bonny, Bellevue Cotton Mills, Skipton.
1863. Fisher, John, Priory Street, Dudley.
1863. Forster, George Emmerson, Contractor's Office, Washington, County Durham.
1865. Gössell, Otto, 22 Moorgate Street, London, E.C.
1865. Hall, John, 56 King Street, Manchester.
1869. Jones, John, Iron Trade Offices, Royal Exchange, Middlesbrough.
1858. Lawton, Benjamin C., 44 Westgate Street, Newcastle-on-Tyne.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Associate.*)
1865. Longsdon, Alfred, 11 New Broad Street, London, E.C.
1860. Manby, Cordy, Tower Street, Dudley.
1868. Matthews, Thomas Bright, Globe Steel Works, Sheffield.
1867. Neave, William Alexander, Poste Restante, Lausanne, Switzerland.
1863. Nichols, William, Midland Copper Works, Guild Street, Burton-on-Trent.
1865. Parry, David, Leeds Iron Works, Leeds.
1864. Parsons, Charles T., Ann Street, Birmingham.
1856. Pettifor, Joseph, Midland Railway, Derby.
1861. Ratcliff, Charles, Wyddrington, Edgbaston, Birmingham.
1867. Roe, Thomas, Jun., Siddals Road, Derby.

1866. Scott, John Peers, 10 Tib Lane, Cross Street, Manchester.
1859. Sherriff, Alexander Clunes, M.P., Great Western Railway, Worcester.
1863. Storey, Thomas R., Deptford Brass Works, Sunderland.
1864. Tennant, John, St. Rollox Chemical Works, Glasgow. (*Life Associate.*)
1864. Thornton, Falkland Samuel, Bradford Street, Birmingham.
1869. Varley, John, Cyclops Steel and Iron Works, Sheffield.
1865. Warden, Thomas, Lionel Street, Birmingham.
1848. Warden, William Marston, Broad Street, Birmingham.
1858. Waterhouse, Thomas, Claremont Place, Sheffield.
1867. Watts, William Thomas, 78 Parade, Birmingham.
1865. Whitley, Joseph, Bowman Lane, Leeds.
1863. Woolley, John, Marehay Colliery, Ripley, near Derby.

## GRADUATES.

1869. Bainbridge, Emerson, Leazes Villa, Newcastle-on-Tyne.
1869. Blake, Frederick William, Birmingham Heath Boiler Works, Birmingham.
1866. Butler, James, care of John O. Butler, Kirkstall Forge, near Leeds.
1866. Butler, Thomas Snowden, Kirkstall Forge, near Leeds.
1867. Cuss, Nevil John, Great Western Railway, Locomotive Department, Swindon.
1867. Downes, James Charles, Midland Railway, Locomotive Department, Derby.
1868. Dugard, William Henry, 77 Lower Loveday Street, Birmingham.
1869. Fenwick, Clennell, 44A Coal Exchange, Lower Thames Street, London, E.C.
1867. Flavel, Sidney, Jun., Eagle Foundry, Leamington.
1850. Glydon, George, Spring Hill Tube and Metal Works, Eyre Street, Birmingham.
1869. Grainger, James Nixon, Public Works Department, Chepank, Madras, India.
1867. Hill, Henry Walker, Notintone Place, Sneinton, near Nottingham.
1867. Holland, George, care of John Holland, Navigation Old Yard, Castle, Northwich.
1866. Humphrys, Robert Harry, Deptford Pier, London, S.E.
1867. Jones, George Edward, Horseley Iron Works, Tipton.
1868. Mappin, Frank, Sheaf Works, Sheffield.
1867. Mayhew, Horace, Mining Engineer, Wigan.
1867. Mitchell, John, Swaithe Colliery, Barnsley.
1868. Moor, William, Jun., Hetton Colliery, Hetton, near Fence Houses.
1867. Pearson, John Edward, Spring Colliery, Ince Hall, near Wigan.
1867. Warden, Howard William, Horseley Iron Works, Tipton.
1868. Wicksteed, Joseph Hartley, Well House Foundry, Meadow Road, Leeds.
1867. Wright, John Roper, Landore Steel Works, Swansea.

# BLAST-FURNACE WASTE GAS.

*Plate I.*

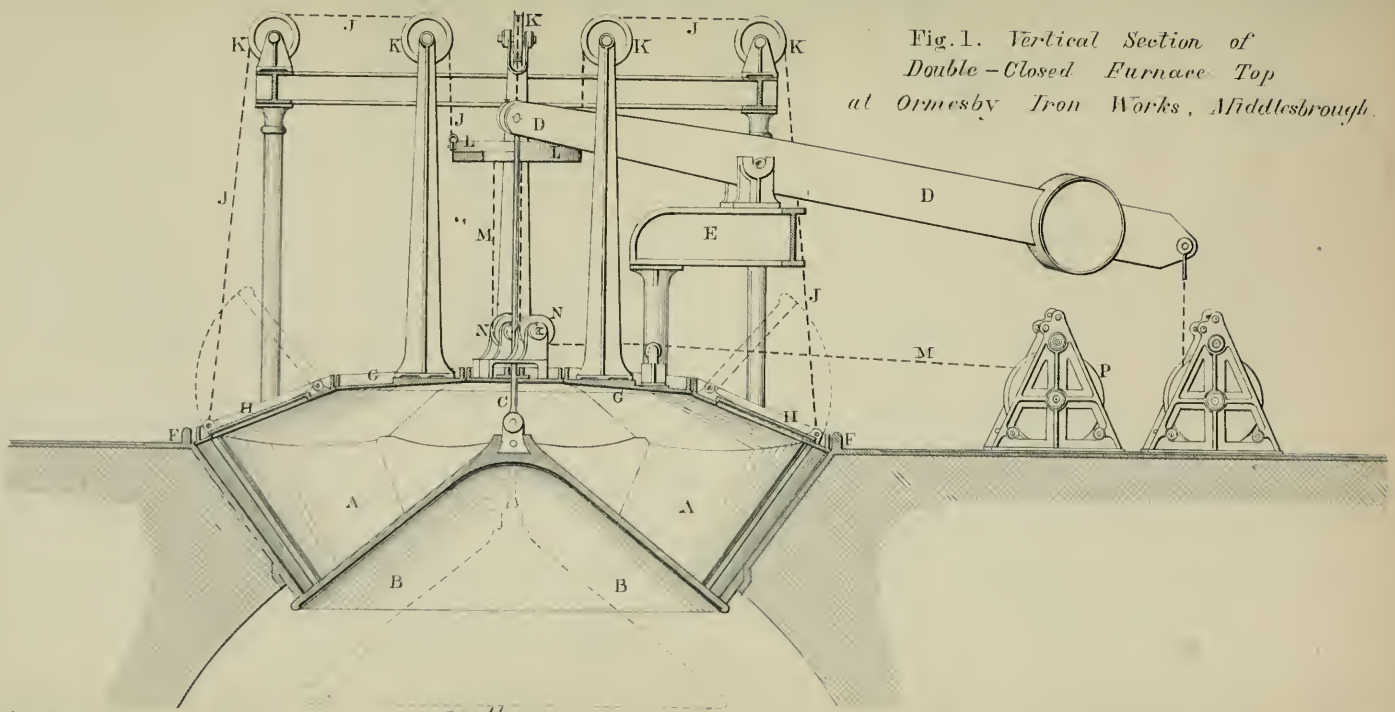



Fig. 1. *Vertical Section of Double-Closed Furnace Top at Ormesby Iron Works, Middlesbrough.*

*(Proceedings Inst. M. E. 1869.)* Scale $\frac{1}{60}$th

0 5 10 15 20 Feet.

# BLAST-FURNACE WASTE GAS.

Plate 2.

Fig. 2. *Plan of Double-Closed Furnace Top at Ormesby Iron Works, Middlesbrough.*

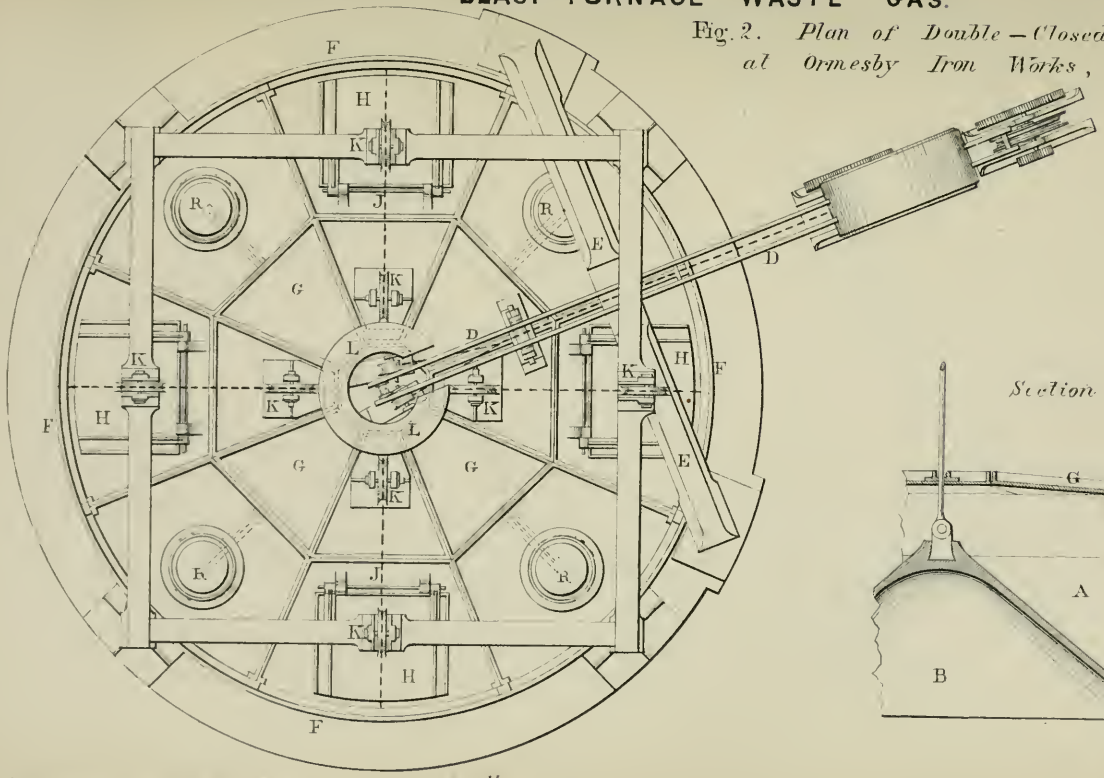
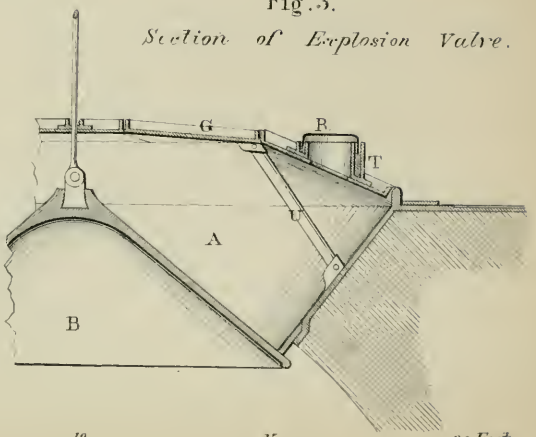



Fig. 3.

*Section of Explosion Valve.*




*(Proceedings Inst. M.E. 1869.)* *Scale* $\frac{1}{60}$*th*

0 5 10 15 20 Feet.

# BLAST-FURNACE WASTE GAS.

*Plate 3.*

*Vertical Sections of Double-Closed Furnace Top at Ormesby Iron Works, Middlesbrough.*

Fig. 4. *Bell closed, Charging Doors open.*

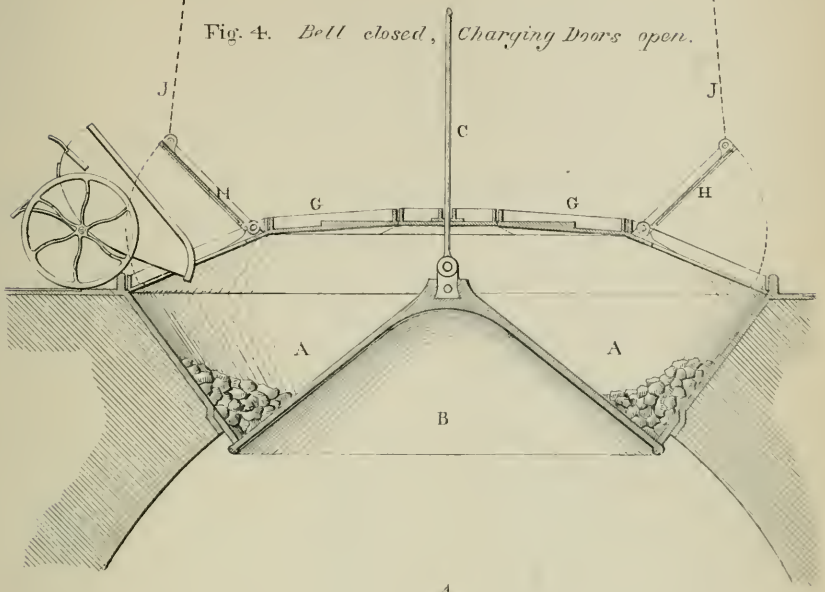
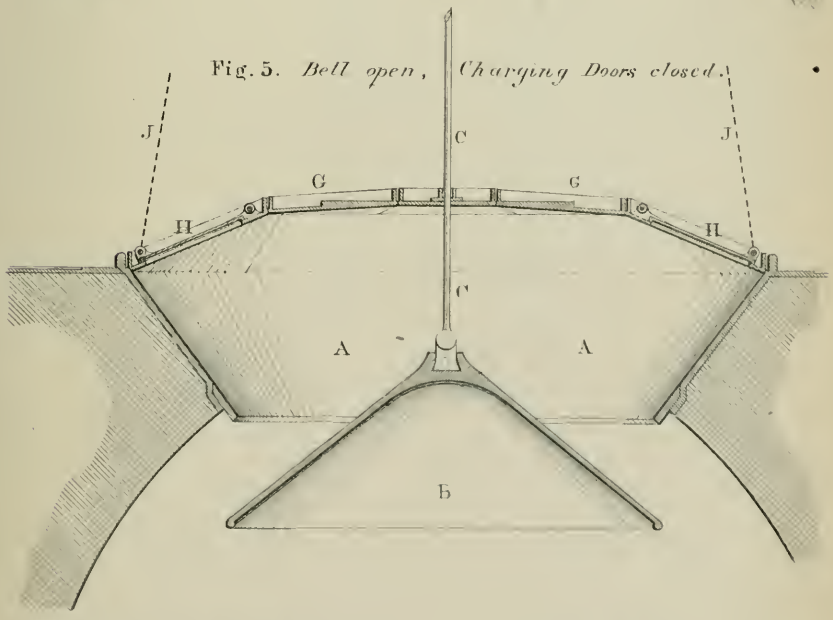



Fig. 5. *Bell open, Charging Doors closed.*




*(Proceedings Inst. M. E. 1869.)*

*Scale* $\frac{1}{60}^{th}$

0 5 10 15 *Feet.*

*Vertical Sections of Blast Furnaces*

*at Ormesby Iron Works, Middlesbrough.*

Fig. 6.

*Large Furnace.*

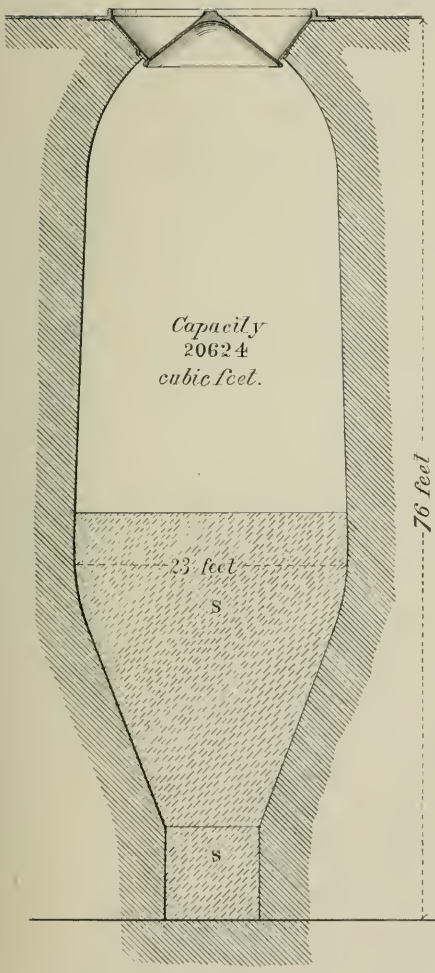
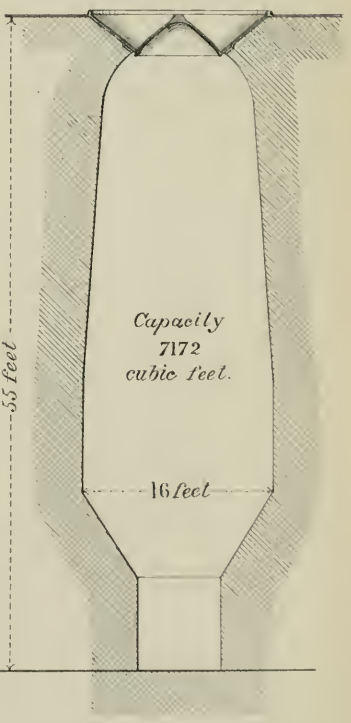



Fig. 7.

*Small Furnace.*




*(Proceedings Inst. M. E. 1869)*

*Scale* $^1/_{200}{}^{th}$

10 5 0 10 20 30 40 50 Feet.

# PROCEEDINGS.

28 January, 1869.

The Twenty-second Anniversary Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 28th January, 1869; John Penn, Esq., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The Secretary then read the following

## ANNUAL REPORT OF THE COUNCIL.

1869.

On the occasion of the Twenty-second Anniversary of the Institution, the Council have great pleasure in congratulating the Members upon the present satisfactory position and the continued progress of the Institution.

The Financial statement of the affairs of the Institution for the year ending 31st December 1868 shows a balance of £5196 17*s.* 3*d.* after the payment of the accounts due to that date. Out of this amount the sum of £4500 has been invested by the Council during the year in London and North Western Railway 4 per cent. Debenture Bonds, registered in the names of Mr. John Ramsbottom, Vice-President, Mr. Frederick J. Bramwell, Vice-President, and Mr. W. Montgomerie Neilson, Member of Council, as interim trustees on behalf of the Institution. The Finance Committee have examined and checked the receipts and payments of the Institution for the last year 1868, and report that the following Balance Sheet rendered by the Treasurer is correct. (*See Balance Sheet appended.*)

The Council report with pleasure the increase in the number of Members that has taken place during the year; the total number of Members of all classes for the year being 825, of whom 4 are Honorary Life Members, 38 are Associates, and 20 are Graduates, giving an effective increase of 34 during the year.

The following deceases of Members of the Institution have occurred during the past year 1868:—

| | |
|---|---|
| Samuel H. Blackwell, . . . . | Dudley. |
| George H. Bovill, . . . . | London. |
| William Middleton, . . . . . | Birmingham. |
| Frederic C. Reynolds, . . . | London. |
| Isaac Smith, . . . . . | Birmingham. |
| Francis Wise, . . . . . | London. |

Two of these deceased Members, Mr. Bovill and Mr. Middleton, had been Members of the Institution from its commencement; and to Mr. Blackwell's death the Council have to refer with special regret, as a great public loss, from his high scientific attainments and his prominent position in connection with the modern improvements in the iron manufacture of this country.

The Council have the pleasure of acknowledging the following Donations to the Library of the Institution during the past year; and also of expressing their thanks to the Donors for the valuable and acceptable additions they have presented. The Council wish to urge on the attention of the Members the important advantage of obtaining a good collection of Engineering Books, Drawings, and Models or Specimens of interest in the Institution, for the purpose of reference by the Members personally or by correspondence; and they trust this desirable object will be promoted by the Members generally, so that by their united aid it may be efficiently accomplished. Members are requested to present copies of their Works to the Library of the Institution.

## LIST OF DONATIONS TO THE LIBRARY.

Bergeron's Manuel du Tourneur; from the President.

Collection of Engineering Drawings from the Ecole Impériale des Ponts et Chaussées, Paris.

Abridgments and Indexes &c. of British Patents; from the Commissioners of Patents.

Report on the Lancashire and Cheshire Steam Coals; from Mr. Lavington E. Fletcher.

Report of the Irish Railway Commission; from the Commissioners.

On Waves which travel along with Ships, by W. J. Macquorn Rankine; from the author.

Photograph of the Grand River Viaduct on the Mauritius Railway, blown down by a hurricane; from Mr. James R. Mosse.

Proceedings of the Institution of Civil Engineers; from the Institution.

Proceedings of the French Institution of Civil Engineers; from the Institution.

Bulletin of the French Society for the Encouragement of National Industry; from the Society.

Transactions of the Institution of Civil Engineers of Ireland; from the Institution.

Report of the British Association for the Advancement of Science; from the Association.

Transactions of the North of England Institute of Mining Engineers; from the Institute.

Proceedings of the South Wales Institute of Engineers; from the Institute.

Transactions of the Institution of Engineers in Scotland; from the Institution.

Transactions of the Society of Engineers; from the Society.

Proceedings of the Royal Institution of Great Britain; from the Institution.

Journal of the Hannover Architect and Engineers' Society; from the Society.

Journal of the Saxon Society of Engineers; from the Society.

Journal of the Norwegian Polytechnic Society; from the Society.

Proceedings of the Bombay Mechanics' Institution; from the Institution.

Report of the Smithsonian Institution for 1866; from the Institution.

Journal of the Royal United Service Institution; from the Institution.

Transactions of the Royal Scottish Society of Arts; from the Society.

Proceedings of the Philosophical Society of Glasgow; from the Society.

Report of the Royal Cornwall Polytechnic Society; from the Society.

Reports of the Manchester Association for the Prevention of Steam Boiler Explosions; from Mr. Lavington E. Fletcher.

Report of the Manchester Boiler Insurance Company; from Mr. Robert B. Longridge.

Reports of the Midland Steam Boiler Association; from Mr. Edward B. Marten.

Report of the British Association of Gas Managers; from the Association.

United States Patent Office Reports; from the Commissioner.

Description of the "Public Ledger" Office, Philadelphia; from Mr. George W. Childs.

Journal of the Board of Arts and Manufactures for Upper Canada; from the Board.

Journal of the Society of Arts; from the Society.
The Engineer; from the Editor.
Engineering; from the Editor.
The Mechanics' Magazine; from the Editor.
The Artizan Journal; from the Editor.
The Practical Mechanic's Journal; from the Editor.
The Mining Journal; from the Editor.
The Railway Record; from the Editor.
The Steam Shipping Journal; from the Editor.

The Council have great satisfaction in referring to the number and character of the Papers that have been brought before the meetings during the past year, and the practical value and interest of the communications and the discussions that took place upon them, which form a valuable addition to the Proceedings of the Institution. The Council request the special attention of the Members to the importance of their aid and co-operation in carrying out the objects of the Institution and maintaining its advanced position, by contributing papers on Engineering subjects that have come under their observation, and communicating the particulars and results of executed works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended and other subjects advantageous to the Institution.

The following Papers have been read at the Meetings during the past year:—

On the Transmission of Power by Water Pressure, with the application to Railway Goods Stations, Forge and Foundry Cranes, and Blast-Furnace Hoists; by Sir William G. Armstrong.

On the Allen Engine and Governor; by Mr. Charles T. Porter.

Description of the American Dovetailing Machine; by Mr. John Robinson.

On an improved Cupola for Iron Foundries; by Mr. Jacob Eichhorn.

Description of the Machinery for the Manufacture of the Boxer Cartridges; by Mr. Thomas Greenwood.

On the application of Machinery to Coal Cutting; by Mr. John Fernie.

Description of a Travelling Crane worked by Clip Drum and Wire Rope; by Mr. John Fernie.

On the Corliss Expansion Gear for stationary engines; by Mr. William Inglis.

On the Machinery for Weaving Brussels Carpet by power; by Mr. William Weild.

On the further utilisation of the Waste Gas from Blast Furnaces, and the Economy of Coke due to increased Capacity of Furnace; by Mr. Charles Cochrane, of Dudley.

On an improved Friction Coupling and Break, and its application to Hoists, Windlasses, and Shafting, &c.; by Mr. Thomas A. Weston.

On the Moulding of Toothed Wheels, and an improved Wheel Moulding Machine; by Mr. George L. Scott.

The Council have particular pleasure in referring to the great success and interest of the Annual Meeting of the Institution that was held in Leeds last summer during the time of the National Art Treasures Exhibition; and in expressing their special thanks to the authorities of the Philosophical Hall, and to the Honorary Local Secretaries, Mr. John Fernie and Mr. William E. Marshall, and the other local Members, for the very excellent arrangements and the handsome reception given to the Members on the occasion; and also their thanks to the railway authorities for the special arrangements granted for the excursions; and to the proprietors of the works that were so liberally thrown open to the inspection of the Members, for the valuable opportunity afforded to the Members for seeing their works. The Council refer particularly to the advantage afforded to the Members in the opportunity so kindly provided them on that occasion for witnessing the action of the two different Coal-Cutting Machines at work in the same colliery, and the working of the new Corliss Engines at Saltaire. The Council look forwards with confidence to the advantages arising from these Annual Meetings of the Institution in different localities, from the facilities afforded by them for the personal communication of the Members in different districts, and from the opportunities of visiting the important Engineering Works that are so liberally thrown open to their inspection on those occasions.

The Council have had under consideration the following verbal corrections in the Rules, for the purpose of expressing more clearly the practice of the Institution, and they now recommend these corrections for adoption:—

In place of the Rule, that "All Subscriptions are to date from January 1st in each year,"—the following Rule to be substituted:—"All Subscriptions are to become due on January 1st in each year for the year then commencing; and the first subscription of New Members is to date from January 1st in the year of their election."

In place of the Rule, that "Any Member, Graduate, or Associate, leaving his subscription in arrear for two years, is to have his name struck off the List,"—the following Rule to be substituted:—"If any Member, Graduate, or Associate, shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the List of Members by the Council at any time afterwards; but he shall nevertheless be liable to pay the arrears of subscription due at the time of his name being so struck off."

In place of the Rule, that "All the property of the Institution is to be held by the Council, in trust for the Institution,"—the following Rule to be substituted:—"All the moveable property of the Institution is to be held by the Council, in trust for the Institution."

The President, Vice-Presidents, and five of the Members of the Council in rotation, go out of office this day, according to the rules of the Institution; and the ballot will be taken at the present Meeting for the election of the Officers and Council for the ensuing year.

## SUBJECTS FOR PAPERS.

Steam Engine Boilers, particulars of construction—form and extent of heating surface—relative value of radiant surface and flue surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—pressure gauges—safety valves—water gauges—explosion of boilers, and means of prevention—effects of heat on the metal of boilers, low-pressure and high-pressure—steel boilers—cast-iron boilers—welded boilers—incrustation of boilers, and means of prevention—corrosion of boilers, and means of prevention—effects of surface condensers on the metal of boilers—evaporative power and economy of different kinds of fuel, coal, wood, charcoal, peat, patent coal, and coke—moveable grates, and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed water—mode of feeding—use of injector—circulation of water.

Steam Engines—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single cylinder engines—combined engines—compound cylinder engines—comparative advantages of direct-acting and beam engines—engines for manufacturing purposes—horizontal and vertical—condensing and non-condensing—injection and surface condensers—air pumps—governors—valves—bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

Pumping Engines, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—construction of pumps—plunger pumps—bucket pumps—particular details of different valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.—sewage pumping engines—details of pit work of pumping engines in mines.

Blast Engines, best kind of engine—size of steam cylinder, strokes per minute, and horse power—details of boilers—size of blowing cylinder, and strokes per minute—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from air main and steam cylinder.

Marine Engines, power of engines in proportion to tonnage—different constructions of engines, double-cylinder engines, trunk engines—three-cylinder engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—salinometers—weight of machinery and boilers—kind of paddle wheels—speed obtained in British war steamers, in British merchant steamers, and in Foreign ditto, with particulars of the construction of engines with paddle wheels, &c.—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—reaction propellers—governors and storm governors.

Rotary Engines, particulars of construction and practical application—details of results of working.

Locomotive Engines, particulars of construction, details of experiments, and results of working—consumption of fuel—relative value and evaporative duty of coke and coal—consumption of smoke—use of wood and construction of spark arresters—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast pipe—construction of pistons, valve gear, expansion gear, &c.—indicator diagrams—expenses of working and repairs—means of supplying water to tenders—locomotives for steep gradients and sharp curves—distribution of weight on wheels.

Agricultural Engines, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural purposes—barn machinery—field implements—traction engines, particulars of performance and cost of work done.

Caloric Engines—engines worked by gas, or explosive compounds—electro-magnetic engines—particulars and results.

Hydraulic Engines, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—construction of joints—hydraulic rams.

Water Wheels, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy—transmission of power to distant points.

Wind Mills, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

Corn Mills, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—advantages of regularity of motion.

Sugar Mills, particulars of construction and working—results of application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

Oil Mills, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

Cotton Mills, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning, carding, and winding machinery, &c.

Calico-Printing and Bleaching Machinery, particulars of improvements.

Wool Machinery, carding, combing, roving, spinning, &c.

Flax Machinery, manufacture of flax, china grass, and other fibrous materials, both in the natural length of staple and when cut.

Weaving Machinery, for manufacture of different materials—improvements in looms, &c.

Rope-Making Machinery—hemp and wire ropes, comparative strength, durability, and cost—steel wire ropes—transmission of power by ropes, percentage of loss, distance, wear of ropes, &c.

Saw Mills, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws.

Wood-Working Machines, morticing, dovetailing, planing, rounding, and surfacing—copying machinery.

Glass Machinery—manufacture of plate and sheet glass—construction of heating furnaces, annealing kilns, &c.—grinding and polishing machinery.

Lathes, Planing, Boring, Drilling, Slotting, and Shaping Machines, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

Rolling Mills, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders—rolling of armour plates—reversing rolls.

Steam Hammers, improvements in construction and application—friction hammers—air hammers.

Riveting, Punching, and Shearing Machines, worked by steam or hydraulic pressure—direct-acting and lever machines—portable machines—comparative strength of drilled and punched plates—rivet-making machines.

Stamping and Coining Machinery, particulars of improvements, &c.

Locks, and lock-making machinery—iron safes.

Paper-Making and Paper-Cutting Machines, new materials and results.

Printing Machines, particulars of improvements, &c.—machines for printing from engraved surfaces—type composing and distributing machines.

Water Pumps, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

Air Pumps, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

Hydraulic Presses, facts relating to the best construction, means of working, and application—economical limit of pressure.

Rotary and Centrifugal Pumps, ditto ditto ditto.

Fire Engines, hand and steam, ditto ditto ditto.

Sluices and Sluice Cocks, worked by hand or hydraulic power, ditto.

Cranes—steam, hydraulic, and pneumatic cranes—travelling cranes.

Lifts for raising railway wagons—hoists for warehouses—safety apparatus.

Toothed Wheels, best construction and form of teeth—results of working—strength of iron and wood teeth—moulding by machinery.

Driving Belts and Straps, best make and material, leather, gutta-percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

Dynamometers, construction, application, and results of working.

Decimal Measurement—application of decimal system of measurement to mechanical engineering work, drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

Strength of Materials, facts relating to experiments, and general details of the proof of girders, &c.—girders of cast and wrought iron, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

Durability of Timber of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

Corrosion of Metals by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature and preventives.

Alloys of Metals, facts relating to different alloys.

Friction of Various Bodies, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—

wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials, best plans for oil tests—friction breaks.

Iron Roofs, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast-iron, wrought-iron, timber, &c.—best construction form, and materials—details of large roofs and cost.

Fire-proof Buildings, particulars of construction—most efficient plan—results of trials.

Chimney Stacks of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

Bricks, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry-clay bricks—machines for brick-making—burning of bricks.

Gas Works, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas meters—self-regulating meters—pressure of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure—lighting railway trains with gas.

Water Works, facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durability of pipes and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—sluices and self-acting valves—machinery for working sluices—water meters, construction and working.

Well Sinking and Artesian Wells, facts relating to—boring tools, construction and mode of using.

Tunnelling Machines, particulars of construction, and results of working.

Cofferdams and Piling, facts relating to construction—cast-iron sheet piling.

Piers, fixed and floating, and pontoons, ditto ditto.

Pile Driving Apparatus, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles—pile shoes.

Dredging Machines, particulars of improvements—application of dredging machines—power required and work done.

Diving Bells and Diving Dresses, facts relating to the best construction.

Lighthouses, cast-iron and wrought-iron, ditto ditto.

Ships, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast—steel masts and yards, and wire-rope rigging—comparative strength and advantage of iron and wood ships—arrangements for docking and repairing ships—steering gear—application of steam power to steering.

Guns, cast-iron, wrought-iron, and steel—manufacture and proof—rifling—manufacture of shot and shells.

Small Arms, machinery for manufacture of rifles and cartridges, &c.

Mining Operations, facts relating to mining—modes of working and proportionate yield—coal-cutting machines—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—underground conveyance—stone-breaking machines—mode of breaking, pulverising, and sifting various descriptions of ores.

Blasting, facts relating to blasting under water, and blasting generally—use of gun-cotton, &c.—effects produced by large and small charges of powder—arrangement of charges.

Blast Furnaces, shape and size—consumption of fuel—yield and quality of metal—pressure of blast—horse power required—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot-blast ovens—pyrometers—construction of tuyeres—means and results of application of waste gas from close-topped and open-topped furnaces—preparation of materials for furnace and mode of charging.

Puddling Furnaces, best forms and construction—worked with coal, charcoal, &c.—application of machinery to puddling.

Heating Furnaces, best construction—consumption of fuel, and heat obtained.

Cupolas, construction and proportions—improvements in means of blowing—results of working, and economy of fuel.

Converting Furnaces, construction of furnaces—manufacture of steel—case-hardening, &c.—converting materials employed.

Smiths' Forges, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

Smiths' Fans and Fans generally, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains—mechanical ventilation and warming of public buildings.

Coke and Charcoal, particulars of the best mode of making, and construction of ovens, &c.—open coking, mixtures of coal slack and other materials—evaporative power of different varieties—peat, manufacture of compressed peat.

Railways, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection,

deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

Switches and Crossings, particulars of improvements, and results of working.

Turntables, particulars of various constructions and improvements—engine turntables.

Signals for stations and trains, and self-acting signals.

Electric Telegraphs, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying, and machinery employed.

Railway Carriages and Wagons, details of construction—proportion of dead weight.

Breaks for carriages and wagons, best construction—self-acting breaks—continuous breaks.

Buffers for carriages, &c., and station buffers—different constructions and materials.

Couplings for carriages and wagons—safety couplings.

Springs for carriages, &c.—buffing, bearing, and draw springs—range, and deflection per ton—particulars of different constructions and materials, and results of working.

Railway Wheels, wrought-iron, cast-iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought-iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of weldless tyres, and solid wrought-iron wheels.

Railway Axles, best description, form, material, and mode of manufacture.

## PREPARATION OF PAPERS.

The Papers to be written in the third person, on foolscap paper, on one side only of each page, leaving a clear margin of an inch width on the left side. In the subjects of the papers, extracts from printed publications and questions of patent right or priority of invention are not admissible.

The Diagrams to be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper. Enlarged details to be added for the illustration of any particular portions, drawn full size or magnified, with the different parts strongly coloured in distinctive colours. Several explanatory diagrams drawn roughly to a large scale in dark pencil lines and strongly coloured are preferable to a few small-scale finished drawings. The scale of each diagram to be marked upon it.

# INSTITUTION OF MECHANICAL ENGINEERS.

## BALANCE SHEET.

*For the year ending* 31*st December*, 1868.

| *Cr.* | £ | *s.* | *d.* |
|---|---|---|---|
| By Balance 31st December, 1867 | 4717 | 13 | 11 |
| „ Subscriptions from 46 Members in arrear | 138 | 0 | 0 |
| „ ditto from 2 Associates in arrear | 6 | 0 | 0 |
| „ ditto from 632 Members for 1868 | 1896 | 0 | 0 |
| „ ditto from 32 Associates for 1868 | 96 | 0 | 0 |
| „ ditto from 18 Graduates for 1868 | 36 | 0 | 0 |
| „ ditto from 5 Members in advance for 1869 | 15 | 0 | 0 |
| „ Entrance Fees from 54 New Members | 108 | 0 | 0 |
| „ ditto from 2 New Associates | 4 | 0 | 0 |
| „ ditto from 4 New Graduates | 4 | 0 | 0 |
| „ Sale of Extra Reports | 17 | 6 | 0 |
| „ Interest from Bank *. | 36 | 3 | 8 |
| | £7074 | 3 | 7 |

* Note.—Additional Interest due to 31 Dec. 1868 from 5 Aug. on £4500 invested, 148 days at 4 per cent. = £72 : 19 : 9, paid since 31st December.

| *Dr.* | | | | £ | *s.* | *d.* |
|---|---|---|---|---|---|---|
| To Printing and Engraving Reports of Proceedings | 769 | 4 | 8 | | | |
| Less Authors' copies of Papers, repaid | 7 | 13 | 0 | 761 | 11 | 8 |
| „ Stationery and Printing of Circulars &c. | | | | 68 | 11 | 6 |
| „ Office Expenses, Clerks, and Petty Disbursements | | | | 110 | 15 | 11 |
| „ Coals, Gas, and Water | | | | 20 | 14 | 5 |
| „ Expenses of Meetings | | | | 140 | 5 | 6 |
| „ Fittings and Repairs | | | | 7 | 19 | 8 |
| „ Travelling Expenses | | | | 47 | 1 | 4 |
| „ Parcels | | | | 6 | 5 | 10 |
| „ Postages | | | | 93 | 17 | 3 |
| „ Salaries | | | | 500 | 0 | 0 |
| „ Insurance | | | | 2 | 8 | 3 |
| „ Rent and Taxes | | | | 117 | 15 | 0 |
| Balance 31st Dec. 1868; Invested | 4500 | 0 | 0 | | | |
| In Bank | 696 | 17 | 3 | 5196 | 17 | 3 |
| | | | | £7074 | 3 | 7 |

28*th January*, 1869.

(Signed) SAMPSON LLOYD, WALTER MAY, } Finance Committee.

# MEMOIRS

## OF MEMBERS DECEASED IN 1868.

Samuel Holden Blackwell was born near Worcester on 8th May 1816. At an early age he became engaged in the iron trade in South Staffordshire, and was for many years the proprietor of numerous blast furnaces, and of mills and forges, in the neighbourhood of Dudley and Bilston. He was also engaged at various periods in large collieries in Monmouthshire; and in the mining of iron ore in the Forest of Dean, in Exmoor, in Northamptonshire, and near Whitehaven. Shortly before his death he was also occupied with blast furnaces at Ynisedwyn in the anthracite district of Glamorganshire, north of Swansea. At an early period of his life he paid much attention to the geological features of the South Staffordshire coalfield; and at the first Birmingham meeting of the British Association in 1839 he read a paper on the rocks of basaltic origin which occur in that coalfield, giving the first connected account of the intruded beds of green rock that extend unconformably through the coalfield from the Rowley hills to the neighbourhood of Wednesfield and Walsall. The leading faults which traverse the coalfield were first collected and laid down by him on the ordnance map of South Staffordshire; and the data collected by him were afterwards used largely in preparing the map of the geological survey. He was the first to call public attention to the extensive deposits of iron ore in Northamptonshire, to trace them northwards through Leicestershire into Lincolnshire, and to introduce the smelting of these ores in South Staffordshire. He paid much attention to the question of utilising the waste gas from blast furnaces; and in 1852 read a paper to the Institution

giving the results of his experience upon this subject in various districts. He was a Member of the Institution from 1851, and for some years one of the Vice-Presidents. He died at Birmingham on 25th March 1868, in the fifty-second year of his age, after a long and painful illness.

George Hinton Bovill was born in London in 1821, and was originally engaged in commercial pursuits; at the age of twenty-one he joined the firm of Swayne and Co., Millwall, in the manufacture of railway wheels and machinery. He was specially known in connection with the important improvements introduced by him in the grinding of corn, by the use of an air blast and exhaust between the millstones; the plan was first adopted in the government dockyards, and its advantages were found to be so great that it became generally used by millers. He was latterly connected with the Millwall Iron Works, and his last work was the contract for the construction of the iron forts at Plymouth, now in course of erection from the designs of the war department. He was a brother of Sir William Bovill, the Lord Chief Justice of the Common Pleas; and was a Member of the Institution from the commencement in 1847. His death took place at Malvern on 9th May 1868, after a long and severe illness, at the age of forty-seven.

William Middleton was born in 1795 at Smethwick near Birmingham, and served his apprenticeship with Messrs. Boulton and Watt, Soho Foundry, in whose employ he remained during the time that James Watt, William Murdock, and others were connected with those celebrated works; and he continued there for upwards of twenty years, part of the time as foreman. In 1834 he commenced business as an engineer, machinist, and manufacturer of railway plant; and for more than thirty years carried on the Vulcan Foundry, Birmingham, during which time he executed many extensive works. He was a Member of the Institution from the commencement in 1847. His health was declining for three years previous to his death, which took place on 23rd November 1868, at the age of seventy-three.

Frederic Cornell Reynolds was born at Wormsley Grange, Herefordshire, on 18th December 1836, and was first engaged in the drawing office at the Butterley Iron Works in 1853, where he continued for two years. From that time he was principal assistant to Mr. F. J. Bramwell in London. He died in London on 1st September 1868, at the age of thirty-one, from the effects of injuries received during the disastrous hurricane that occurred at the island of St. Thomas, West Indies, on 29th October 1867, where he was engaged in superintending the raising of the floating dock, which had been sent out from England for the harbour of St. Thomas. He became a Member of the Institution in 1866.

Isaac Smith was born at Kidderminster on 22nd September 1822, and was apprenticed to his uncle, Mr. Josiah Mason of Birmingham, in the manufacture of steel pens and split rings; and he continued with him until his death, which took place on 21st January 1868 at the age of forty-five, having contributed much by his perseverance and energy to the success of the works. For several years past he had devoted a large amount of attention to the ventilation and sanitary arrangements of some extensive charitable institutions erected by Mr. Mason in the neighbourhood. He was quick and original in the conception of scientific laws and principles, and particularly anxious to investigate all new subjects connected with science or philosophy. He became a Member of the Institution in 1858.

Francis Wise was born in London on 30th July 1820, and in 1836 was articled to Messrs. Whitworth and Co., Manchester, and was subsequently for several years their principal draughtsman. He afterwards practised for some years in Manchester as a consulting engineer, and then removed to Jersey, where he was engaged in designing steam engines and millwork, and in superintending their erection; and some special machinery for works at Fort Regent was carried out from his designs. Afterwards he went to Ghent in Belgium, where he managed the general engineering works of M. Carels, and was engaged in designing steam engines, machinery, and

small steam vessels. In 1855 he settled in London as an engineer and patent agent, latterly associated with his son; and paid great attention to the introduction of the Field boiler and the burning of liquid fuel. During the last three or four years he suffered from loss of power in the limbs by paralysis, and died at Greenhithe on 29th December 1868, aged forty-eight years. He became a Member of the Institution in 1863.

The CHAIRMAN congratulated the Members upon the very successful progress made by the Institution, and its extending importance and value; he had felt it a special honour and gratification to fill the office of President of the Institution, and should always have great pleasure in promoting the interests of the Institution by every means in his power.

He moved that the Report of the Council be received and adopted, which was passed.

The CHAIRMAN announced that the Ballot Lists had been duly opened, and the following Officers and Members of Council were found to be elected for the ensuing year:—

PRESIDENT.

| | |
|---|---|
| SIR WILLIAM G. ARMSTRONG, | Newcastle-on-Tyne. |

VICE-PRESIDENTS.

| | |
|---|---|
| JOHN ANDERSON, | Woolwich. |
| FREDERICK J. BRAMWELL, | London. |
| THOMAS HAWKSLEY, | London. |
| SAMPSON LLOYD, | Wednesbury. |
| JOHN RAMSBOTTOM, | Crewe. |
| C. WILLIAM SIEMENS, | London. |

COUNCIL.

| | |
|---|---|
| JOHN FERNIE, | Leeds. |
| SIR CHARLES FOX, | London. |
| WALTER MAY, | Birmingham. |
| JOHN ROBINSON, | Manchester. |
| PERCY G. B. WESTMACOTT, | Newcastle-on-Tyne. |

PAST-PRESIDENTS.

*Ex-officio permanent Members of Council.*

| | |
|---|---|
| WILLIAM FAIRBAIRN, | Manchester. |
| JAMES KENNEDY, | Liverpool. |
| ROBERT NAPIER, | Glasgow. |
| JOHN PENN, | London. |
| JOSEPH WHITWORTH, | Manchester. |

COUNCIL.

*Members of Council remaining in office.*

| | |
|---|---|
| Charles Edwards Amos, | London. |
| William Clay, | Liverpool. |
| Charles Cochrane, | Dudley. |
| Edward A. Cowper, | London. |
| Edgar Gilkes, | Middlesbrough. |
| Thomas Greenwood, | Leeds. |
| George Harrison, | Birkenhead. |
| William Menelaus, | Dowlais. |
| W. Montgomerie Neilson, | Glasgow. |
| Charles P. Stewart, | Manchester. |

TREASURER.

| | |
|---|---|
| Henry Edmunds, | Birmingham. |

SECRETARY.

| | |
|---|---|
| William P. Marshall, | Birmingham. |

ASSISTANT SECRETARY.

| | |
|---|---|
| Alfred Bache, | Birmingham. |

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The following New Members were also elected:—

MEMBERS.

| | |
|---|---|
| Alfred Elwell, | Wednesbury. |
| William Horatio Harfield, | London. |
| David Marr Henderson, | Shanghai, China. |
| Ferdinand Kohn, | London. |
| Thomas Parker, | Derby. |
| William Hall Pearson, | Birmingham. |
| Thomas James Vickers Wood, | Cleckheaton. |

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A supplementary paper was then read "On the further utilisation of the Waste Gas from Blast Furnaces, and the Economy of Coke due to increased Capacity of Furnace," by Mr. Charles Cochrane, of Dudley; in continuation of the Paper and Discussion upon the same subject at the previous meeting of the Institution in November, 1868.

# ON THE FURTHER UTILISATION OF THE WASTE GAS FROM BLAST FURNACES, AND THE ECONOMY OF COKE DUE TO INCREASED CAPACITY OF FURNACE.

By Mr. CHARLES COCHRANE, of Dudley.

(*Read at the Meeting on 5th November*, 1868.)

The subject of the closing of Blast Furnace tops has been brought before the Institution by the writer on two former occasions, when the effect was described of two different systems of filling upon the distribution of material in the furnace: tending to show the superiority in the Cleveland district of the old form of charging bell and hopper over any other plan that has been introduced for taking off the Waste Gas. The rapid strides which have been made during the past few years in that district—the large reduction in the consumption of coke effected by the use of colossal furnaces and the employment of higher temperatures of blast—the desirability of avoiding entirely the use of coals for boilers and stoves—and the importance of making the supply of the gas permanent at every point where it is consumed—combine to render any plan valuable which will prevent the waste still going on at the majority of blast furnaces in that and other districts, where the bell and hopper arrangement is in use. Not that such a plan will in all cases prove immediately advantageous: for notwithstanding the loss that takes place of at least $1\frac{1}{2}$ hour out of every 24 hours in the supply of gas from a furnace, by reason of the delay in lowering and raising the bell in the ordinary arrangement, there is still a sufficiency of gas, and some to spare, from the best constructed furnaces in the district. The effect of lowering the bell at charging time is to

extinguish the flame temporarily at its place of combustion, by checking the supply of gas; in consequence of which it is frequently necessary to keep some coals constantly burning there, in order to prevent the disastrous explosions which have occasionally taken place at the time of restoring the supply of gas. The writer anticipates that still further improvements will be made in the economy of blast furnaces; and it is a certain result of any further reduction in consumption of coke in the furnace, that the escaping gas will become more and more impoverished, and will contain more carbonic acid and so much less carbonic oxide.

Under these circumstances he submits in the present paper an arrangement of double-closed furnace top for saving the remaining gas hitherto lost, which has now been in successful operation for nine months at the Ormesby Iron Works, Middlesbrough, and continues to work most satisfactorily. This arrangement is shown in Figs. 1 to 5, Plates 1 to 3; Fig. 1 being a vertical section of the blast-furnace cover and its adjuncts, and Fig. 2 a plan.

The hopper A at the blast-furnace mouth is closed at the bottom as usual by the bell B, Fig. 1, which is raised and lowered by means of the rod C and lever D carried by standards on the girder E. The top of the hopper is closed in by the cover G, formed of cast-iron segment plates bolted together and fitting within a flange F formed round the top edge of the hopper. The central portion of the cover is flat, and is raised slightly above the level of the blast-furnace top, while the sides slope down towards the edge of the hopper. The rod C supporting the charging bell B works through a stuffing-box in the centre of the cover G. In the sloping sides of the cover are the four charging openings provided with doors H, which are hinged at the upper edge; and all four are opened and closed simultaneously by means of the chains J passing over the pulleys K K to the central balance-weight L, from which two chains M are carried under the pulleys N to the windlass P. By hauling in the chains M the balance-weight L is drawn down, and all the doors H are raised simultaneously into the position shown in Fig. 4; and as the weight of the doors is only partially counterbalanced by the weight L, they all close down again of themselves when the chains M

are let out from the windlass. Between each of the charging openings H is provided an explosion valve R, shown in section in Fig. 3, fitting into an annular sand trough T over an opening in the cover G; and the cover G is stayed to the hopper at these points by angle-iron stays U. In actual working however it has been found that the effects of every explosion which has yet occurred have been fully met by the yielding of the charging doors H, and the valves R have not been called into requisition.

In charging the furnace, the doors H are all raised, as in Fig. 4, and the ore and other materials are tipped into the hopper, the bell being closed; after which the doors are again closed, as in Fig. 5, and the bell is then lowered so as to allow the charge to fall into the furnace. With this arrangement the utmost quantity of gas that can escape from the furnace during the operation of charging is only what will fill the space between the bell B and the cover G, the capacity of which is 655 cubic feet.

In reference to the actual economy to be derived from the adoption of this doubly closed furnace top, it should be observed that the number of times the bell has to be raised and lowered per day of 24 hours depends on the rate of driving of the furnace, and the size of the charges; but as an illustration it may be stated that 90 lowerings of the bell per 24 hours are needed at the Ormesby Iron Works to charge 60 "rounds," each round consisting of about 66 cwts. of mine, coke, and limestone together, so that the average of the charges for each lowering of the bell is about 44 cwts. of materials; and the time occupied in lowering the bell and raising it again occupies on an average at least one minute at each charge. This is equivalent to 90 minutes in 24 hours; and therefore with the ordinary bell and hopper not covered in, at least 1-16th of the total volume of gas evolved from the furnace is lost. The escape of gas however takes place not only from the particular furnace at which the bell is lowered, but the escaping volume is increased by the partial escape of gas at the same time from the other furnaces connected with the same general gas main; since the gas seeks the readiest outlet from the

main through the open throat of the furnace in course of being charged. Actual observation has led the writer to the conclusion that the loss of time above stated of one minute at each charge is a fair average; for notwithstanding that three quarters of a minute will suffice in many cases, there are occasions, and these not unfrequent, when the furnace being perhaps too full prevents the bell from clearing itself: and then on being lowered it gets wedged open, and in some cases has been seen to require upwards of five minutes before it could be closed again.

The value of the gas thus lost is readily arrived at as follows. Taking the total make of a large furnace at 325 tons per week, the consumption of coal would be about 70 tons per week for ordinary cast-iron heating stoves, and about 80 tons for boilers; say a total of 150 tons per week, the above proportions being subject to variation at different works according to the class of stoves and boilers that are in use. Assuming, as is approximately the case, that the gas from one furnace can heat boilers and stoves for steam and blast to supply itself, it is obvious that 1-16th of 150 tons is the saving per week effected by the adoption of the double closing arrangement; that is, $9\frac{1}{2}$ tons per week or 494 tons per annum is the saving of coal effected, which at 6*s.* 8*d.* per ton gives £164 per furnace per annum in the Cleveland district. The total outlay to effect this saving has been £200, to cover in the circular opening 17 feet diameter at the top of the furnace.

The convenience of this complete covering in to the chargers, a matter of no small moment, is great. Formerly they ran the risk of being occasionally "gassed" as it is called, from inhaling too much of the noxious gas escaping at the time of lowering and closing the bell, or indeed whenever the junction between the edge of the hopper and the bell is not perfect, so that a more than usual leakage ensues; but with the present double closing arrangement they now run no such risk. From the first day the apparatus has been at work the men have invariably spoken of it with praise; and they enjoy an immunity from escape of gas that has never been experienced previously.

The effect of increased size of furnace in diminishing the consumption of coke in a blast furnace will be seen by making the comparison between the two actual sizes of furnace shown in Figs. 6 and 7, Plate 4; the latter represents a small furnace in the Cleveland district, by which is meant one not exceeding 55 feet in height and 16 feet diameter across the boshes; while Fig. 6 shows a large Cleveland furnace of 76 feet height and 23 feet diameter across the boshes; and the capacities of these two furnaces are respectively 7,172 and 20,624 cubic feet.

Under similar conditions of materials, temperature, pressure of blast, &c., the small furnace working with 1000° Fahr. temperature of blast, and with a calcined ironstone containing about 40 per cent. of iron, requires no less than 30 cwts. of coke to make 1 ton of iron; whereas the large furnace makes the same weight of iron with about 26 cwts. of coke. For on comparing the working of two furnaces of these respective sizes at the Ormesby Iron Works, the actual consumption in the month of August last was 30·8 cwts. of coke per ton of iron in the small furnace, and 26·5 cwts. in the large: showing a saving due to the increased capacity of the large furnace of 4·3 cwts. of coke per ton of iron, which is equivalent to 14 per cent. saving of fuel. These figures include the slight corrections required for difference in temperature of blast at the two furnaces, the average temperature of blast from daily observations throughout the month having been 982° Fahr. at the small furnace, and 1063° at the large one.

The heating effect of the gas evolved has next to be considered. Neglecting ash in the coke, and reducing the above amounts to the loads of ironstone actually carried by 20 cwts. of coke, it will be seen that, the ore containing 40 per cent. of iron, 20 cwts. of coke carry a load of 32·5 cwts. of ironstone in the small furnace and 37·7 cwts. of ironstone in the large furnace: the former load containing 13·0 cwts. of iron, and the latter 15·1 cwts. In each case the 20 cwts. of coke, supposing it pure and free from ash, would generate, according to the chemical proportions, 47 cwts.* of

* $C_1 + O_1 = CO$
or $6 + 8 = 14$
hence $6 : 20 :: 14 : 47$

carbonic oxide; and in order to ascertain the amount of carbonic oxide burnt into carbonic acid, and therefore rendered useless for purposes of further combustion outside the furnace, it is necessary to deduct the portion required for reducing the ore, in the proportion of 42 cwts. of carbonic oxide for each 56 cwts. of iron.* This deduction therefore amounts in the first case to 13·0 cwts. iron $\times \frac{42}{56} = 9{\cdot}8$ cwts. carbonic oxide; and in the second case to 15·1 cwts. iron $\times \frac{42}{56} =$ 11·3 cwts. carbonic oxide. Hence the quantity of available carbonic oxide gas evolved per ton of coke consumed is

in the small furnace $47 - 9{\cdot}8 = 37{\cdot}2$ cwts. of available carb. oxide;

in the large furnace $47 - 11{\cdot}3 = 35{\cdot}7$ cwts. of available carb. oxide.

The foregoing calculation shows the consequences of increased capacity of furnace, so far as regards its immediate effect in reducing the supply of gas available for heating purposes. But there is further to be considered the effect of the consequent increase in the volume of carbonic acid so generated, which itself also requires heating at the place where it is finally delivered to the stoves or boilers. Each 56 cwts. of iron reduced from the peroxide involves the generation of 66 cwts. of carbonic acid. Hence the quantities of carbonic acid evolved in the two furnaces, with the production of 13·0 and 15·1 cwts. of iron as previously ascertained, will be

in the small furnace $13{\cdot}0 \times \frac{66}{56} = 15{\cdot}3$ cwts. of carbonic acid;

in the large furnace $15{\cdot}1 \times \frac{66}{56} = 18{\cdot}2$ cwts. of carbonic acid.

Accordingly in the small furnace, with the load of 32·5 cwts. of ironstone on 20 cwts. of coke, a gas is evolved containing 37·2 cwts. of carbonic oxide and 15·3 cwts. of carbonic acid; whilst in the large furnace, with the load of 37·7 cwts. of ironstone, the gas contains only 35·7 cwts. of carbonic oxide but 18·2 cwts. of carbonic acid.

A calculation from the known proportion of nitrogen in the atmosphere will serve to show in what respect the above figures are modified by the presence of this gas in the gaseous products

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* The chemical action is as follows:—

$$Fe_2O_3 + 3CO = Fe_2 + 3CO_2$$

or $56 + 24 + 42 = 56 + 66$

that is $Fe_2 = 56$ requires $3CO = 42$ for reduction.

of the blast furnace. Every 20 cwts. of pure coke requires 26·7 cwts. of oxygen for combustion into carbonic oxide; and the atmosphere being composed of 77 per cent. nitrogen to 23 per cent. oxygen, 89 cwts. of nitrogen must necessarily accompany this oxygen in the blast supplied to the furnace. The nitrogen remains practically unaltered except in temperature from its entrance to its exit; and hence the following comparison of products evolved from the two furnaces is obtained, the small furnace having a load of 32·5 cwts. of ironstone per ton of coke, and the large one a load of 37·7 cwts. of ironstone:—

| | Available Gas. | Useless Gas. Nitrogen. | | Carbonic Acid. | | Total. |
|---|---|---|---|---|---|---|
| Small furnace . . | 37·2 | + 89 | + | 15·3 | = | 141·5 cwts. |
| Large furnace . . | 35·7 | + 89 | + | 18·2 | = | 142·9 cwts. |

In the former case there is 26·3 per cent., and in the latter 25 per cent. of useful combustible gas, out of the total gas evolved from the furnace.

The effect of this difference is much greater than appears at first sight; for not only is there 4 per cent. less carbonic oxide in the gas evolved from the larger furnace, but the gas leaves the larger furnace at about 110° lower temperature than it does the smaller; and the available gas has in its combustion to heat an increased joint volume of nitrogen and carbonic acid, thus lowering the temperature attainable by combustion. As a practical result obtained by the employment of the gas evolved from a large furnace with such a load as that of 37·7 cwts. of ironstone per ton of coke, it may here be stated that a maximum temperature of blast has been obtained of more than 1400°; and beyond this point, or at least more than a few degrees beyond, it will be impossible to pass by the employment of waste gas. Keeping in view therefore the impoverishing of the gas by further improvements in its application—such as that involved in maintaining uniformly the above temperature where it is now known only as a maximum, or that involved in securing higher temperatures of blast by other means than the employment of gas—it obviously becomes a matter of great importance to economise every cubic foot of gas.

The writer desires now to draw attention to the intimate connection which exists between the difference in temperature of the escaping gas and the economy of coke in the larger furnace over the smaller: the amount of economy being 14 per cent., as has been already seen, when both furnaces are supplied with blast at the same temperature of 1000°, and work under similar conditions in all respects, excepting only size of furnace. The relative capacity of the two furnaces is rendered apparent in the diagram Fig. 6, where the shaded portion SS up to the height of 34 ft. 2 ins. in the larger furnace shows the space occupied by the contents of the smaller one; leaving the enormous space of 13,452 cubic feet above, to perform the apparently insignificant duty of extracting a further 110° of temperature from the escaping gas, since the temperature of the waste gas from the smaller furnace ranges about 670°, whilst from the larger it ranges about 560°. Insignificant however as this difference appears to be, it is the sole further explanation of the economy of 14 per cent. of coke in the larger over the smaller furnace; and it is sufficient to account for that extent of economy, as will now be shown.

It has been seen that the total weight of gas evolved per ton of coke burnt is 141·5 cwts. in the smaller furnace, and 142·9 cwts. in the larger; and the consumption of coke per ton of iron made being 30·8 cwts. and 26·5 cwts. respectively, the weight of gas evolved per ton of iron made is

$$\text{in the small furnace } 141{\cdot}5 \times \frac{30{\cdot}8}{20} = 218 \text{ cwts.}$$

$$\text{and in the large furnace } 142{\cdot}9 \times \frac{26{\cdot}5}{20} = 189 \text{ cwts.}$$

The simple question therefore is, what additional heat is absorbed in the larger furnace by reason of 189 cwts. of gas per ton of iron made escaping at a temperature of 560°, whilst 218 cwts. of gas per ton of iron escape at 670° temperature from the smaller furnace.

On reference to a whole year's working in 1859, the writer finds that the quantity of coal burnt in ordinary cast-iron heating stoves to heat blast for the manufacture of one ton of iron was exactly $5\frac{1}{2}$ cwts., and that over the same period 30·1 cwts. of coke per ton of iron were burnt inside the furnace; and inasmuch as similar materials were used to those now employed, the ironstone yielding

about 40 per cent. of iron, it is fair to infer that then, as now, 960° temperature of blast was being obtained at the expense of $5\frac{1}{2}$ cwts. of coal per ton of iron made. Now 30·1 cwts. of pure coke require for combustion into carbonic oxide 174 cwts. of atmospheric air; consequently $5\frac{1}{2}$ cwts. of coal must actually have heated 174 cwts. of air, when coals were used under similar conditions of stove to those under which the same temperature is now attained by the combustion of waste gas. It is well known however that cast-iron stoves are most extravagant in consumption of fuel; and the writer has no hesitation in saying that the consumption of fuel necessary for heating the 174 cwts. of air to the temperature of 1000° ought to be at most only $4\frac{1}{2}$ cwts. of coal, when economically burnt. If this be granted, a standard of reference is at once obtained by which to arrive at the value of the heat escaping from the large and the small furnace respectively.

The consumption of 30·8 cwts. of coke per ton of iron in the small furnace corresponds to an escaping volume of 218 cwts. of gas passing off at 670° temperature. Hence, assuming the specific heat of the escaping gas to be the same as that of atmospheric air, the quantity of coal requisite for heating the escaping gas to that temperature would be, according to the above proportion,

$$\frac{218}{174} \text{ cwts. gas} \times \frac{670}{1000} \times 4{\cdot}5 \text{ cwts. coal} = 3{\cdot}78 \text{ cwts. coal.}$$

In the large furnace the consumption of 26·5 cwts. of coke per ton of iron corresponds to an escaping volume of 189 cwts. of gas passing off at 560° temperature. Hence

$$\frac{189}{174} \text{ cwts. gas} \times \frac{560}{1000} \times 4{\cdot}5 \text{ cwts. coal} = 2{\cdot}74 \text{ cwts. coal.}$$

The difference 1·04 between these two amounts shows the absorption of heat per ton of iron as represented by coal burnt outside the furnace: that is 1·04 cwts. of coal per ton of iron is so saved when referred to that standard. In this comparison the combustion of the fuel has been considered as extending only to the formation of carbonic oxide instead of carbonic acid; but as four times* the heat is developed

* 1 lb. of carbon burnt into carbonic oxide develops only 2880 units of heat, whilst 1 lb. of carbon burnt into carbonic acid develops about 11,700 units; 1 unit of heat being 1 lb. of water heated 1° Fahr.

by the complete combustion into carbonic acid, the saving effected in the furnace should be four times 1·04, or 4·1 cwts. of coal per ton of iron made. The actual saving effected has been 4·3 cwts. of coke in the furnace, a result which agrees more closely with the above calculation of 4·1 cwts. of coal than is necessary for confirming the correctness of the explanation that the writer has ventured to offer, he believes for the first time, of the real cause of saving in a large furnace compared with a small one.

The above calculations have been submitted by the writer for verification and criticism to the manager at the Ormesby Iron Works, Mr. William Crossley, who has conducted the scientific observations which have assisted in leading the writer to the foregoing conclusions; and he feels it right to give the very satisfactory corroboration received from that gentleman of the conclusions so arrived at.

The conditions being as above stated—that only 189 cwts. of gas per ton of iron escape from the large furnace at 560° temperature, whilst 218 cwts. escape from the small furnace at 670°—it follows that 29 cwts. less gas per ton of iron escape from the large furnace, and that the whole quantity of 189 cwts. which does escape passes off at 110° lower temperature. The actual number of units of heat saved can therefore be readily calculated. Reducing 29 cwts. to lbs., 3248 lbs. heated to 670° escape in excess from the smaller furnace; and reducing 189 cwts. to lbs., 21168 lbs. escape at 110° higher temperature than the equal volume passing off from the larger furnace, which in that case is the total volume.

Taking the specific heat of the escaping gas to be the same as that of nitrogen,* namely 0·275, the units of heat corresponding to the above figures will be

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* Specific Heats, according to De la Roche and Berard:—

| | | |
|---|---|---|
| Water | = | 1·000 |
| Carbonic Oxide | = | 0·288 |
| Nitrogen | = | 0·275 |
| Air | = | 0·267 |
| Oxygen | = | 0·236 |
| Carbonic Acid | = | 0·221 |

$$3248 \times 670° \times 0{\cdot}275 = 598{,}444 \text{ units of heat,}$$
$$21168 \times 110° \times 0{\cdot}275 = 640{,}332 \text{ units of heat;}$$
$$\text{Total } 1{,}238{,}776 \text{ units of heat.}$$

There is thus an excess of 1,238,776 units of heat escaping from the smaller furnace per ton of iron made. But 2880 units represent 1 lb. of carbon burnt into carbonic oxide; hence 1,238,776 units represent 430 lbs. or 3·8 cwts. of coke as the saving per ton of iron in the large furnace. This result presents so near an agreement with the 4·3 cwts. of coke actually saved, and the 4·1 cwts. of coal calculated in the first instance as the amount which should be saved, that no doubt can be felt of the accuracy of the explanation given.

From the data already given it becomes practicable to calculate the maximum limit of size for a blast furnace working in the Cleveland district, beyond which no advantage could possibly accrue: the calcined ironstone used containing about 40 per cent. of iron, and the blast being supplied to the furnace at 1000° Fahr., which is the highest temperature, or nearly so, attainable by cast-iron stoves. This maximum limit of size will be found by ascertaining what further increase in size of furnace would further reduce the temperature of the escaping gas down to the temperature of the external atmosphere, which is the lowest limit possible.

In the furnace already described of 76 feet height and 23 feet diameter across the boshes, of which the capacity is 20,624 cubic feet, the temperature of the escaping gas being 110° lower than in the smaller furnace containing only 7,172 cubic feet, it follows that 13,452 additional cubic feet of space have been needed to produce this absorption of 110°, subject to certain slight corrections which are not material for the present purpose. The temperature of the escaping gas from the larger furnace is 560°, or say 490° above the average temperature of the atmosphere; and assuming that a further addition of 13,452 cubic feet capacity would secure a further reduction of 110° in the above temperature, then $13{,}452 \times \frac{490}{110} + 20{,}624 = 80{,}546$ cubic feet should represent the capacity of such a furnace as would absorb all the escaping heat.*

* See correction of this calculation in the supplementary paper.

But the more nearly two bodies approach each other in temperature, the more difficult is the process of establishing perfect equilibrium; and therefore the capacity of the maximum furnace might even somewhat exceed this size of 80,546 cubic feet, should no other circumstances determine its limits.

Such a furnace as above described should work with as little fuel as 7·35 cwts. of coke per ton of iron, assuming that each 110° reduction in temperature of the escaping gas would be accompanied by the same saving of 4·3 cwts. of coke per ton of iron; for $26{\cdot}5 \text{ cwts.} - (4{\cdot}3 \times \frac{490}{110}) = 7{\cdot}35$ cwts. The furnace would be about 124 feet in height, and 36 feet across the boshes, supposing that every proportion of hearth, throat, and boshes, &c., were maintained the same as in the present large furnace of 76 feet height and 23 feet diameter.

Proceeding to ascertain theoretically the quantity of coke which must be put into a furnace in order to secure the reduction of the ironstone and the carbonisation of the iron, it may be taken that for the purpose of reducing or deoxidising 20 cwts. of iron from the condition of peroxide there are needed 18 cwts. of carbon to each 56 cwts. of iron made,* which gives the consumption as $20 \times \frac{18}{56} = 6{\cdot}43$ cwts. of coke per ton of iron made. For carbonisation it may be assumed that from 4 to 5 per cent. of carbon is needed, say 1 cwt. per ton of iron in addition. This makes a total of 7·43 cwts. of coke per ton of iron, below which a blast furnace could not possibly work.

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* $Fe_2O_3 + 3CO = Fe_2 + 3CO_2$;
that is $Fe_2 = 56$ requires $3C = 18$ for reduction.

(*Discussion at the Meeting on 5th November*, 1868.)

The Chairman (Mr. Bramwell) considered they were much indebted to the author for the paper just read, which drew attention to an important question of a still further saving being practicable in the economy of blast furnaces in the Cleveland district, by a further increase in the capacity of the furnaces.

Mr. C. W. Siemens said he had listened with great pleasure to the paper, combining as it did practical experience with theoretical considerations; and as regarded the chemical part of the question the arguments advanced seemed to be based upon correct chemical proportions, although there was one of the conclusions arrived at that he could not agree with.

In reference to the plan of closing in the charging hopper at the furnace top with the additional covering now described, there could be no doubt that a saving of gas must be thereby effected; and although at first glance it might be thought that the amount of this saving would not be anything material, as the time that the furnace top was open on each occasion of charging seemed only momentary, it appeared from actual observation that this time of opening really amounted altogether to as much as 1-16th of the whole time of working of the furnace, representing a loss of 1-16th of all the gas evolved from the furnace. At the same time this loss was attended with the additional objection of interruption in the flow of gas to the boiler fires and hot-blast stoves where it was employed for heating purposes; and it was a decided advantage that these interruptions were now entirely obviated by the double closing of the furnace top.

With regard to the theoretical minimum consumption of $7\frac{1}{2}$ cwts. of coke in the blast furnace for the reduction of 1 ton of iron from the ore, it was certainly true that, with an ironstone containing 40 per cent. of iron, $6\frac{1}{2}$ cwts. of carbon would suffice to reduce 1 ton of iron from the ore by combining with the oxygen contained in the ore, and 1 cwt. of carbon in addition would be more than sufficient for the carbonisation of the iron, making the $7\frac{1}{2}$ cwts. of carbon per ton of iron; but he did not see that sufficient heat could then be produced by the combustion of that reduced quantity of carbon in the furnace.

Moreover he did not consider that it would be possible in practice to attain to this theoretical minimum consumption of coke by any addition to the height of the blast furnace. A small additional amount of heat might indeed be absorbed from the waste gas by raising the furnaces still higher than at present, but this process could not go on indefinitely, and there would still be a certain surplus of heat that would escape; because the combustion of coke by atmospheric oxygen that was necessary to effect the fusion of a given quantity of reduced ore at a high temperature must always leave a certain margin of heat available for reducing and heating the incoming ore. Moreover as the incoming ore was limited in quantity and possessed only a limited capacity for heat, it followed that even if it were a perfect conductor of heat and presented an unlimited extent of surface for absorbing the heat from the gas, there would still be a certain amount of heat that would escape at the furnace top; and in increasing the height of the furnace, a neutral point would speedily be reached, beyond which no further increase of height would produce any further absorption of heat, for the reason that the quantity of ore charged could not on the average exceed the quantity of ore smelted during the same interval of time, and its relative capacity for heat could not be increased by an augmentation of heat-absorbing surface. The saving consequent upon increased capacity of the blast furnace would continue to increase until a certain minimum consumption of fuel was reached, but this would not be the theoretical minimum assigned by chemical calculations. The ore could not do more than take up a certain amount of heat from the gas; and supposing that its capacity for heat were sufficient to reduce the temperature of the gas down to 500° or 400°, that would be the temperature at which the gas must then escape, and no further saving would be possible. If the relative quantity of ore that could be charged into the furnace were indefinitely great, then indeed the escaping gas could be cooled down as low as the temperature of the external atmosphere; but inasmuch as the quantity of ore charged into the furnace top was the same as the quantity smelted in the lower part of the furnace, this ore could not absorb more than a certain maximum quantity of

heat, and all the surplus heat in the waste gas must escape. There was also the further question whether with anything like such a small proportion of coke a sufficient temperature could be obtained in the furnace to ensure the perfect fusion of the ore: for this purpose an infinitely high temperature of blast would be requisite, but with a blast at only 1000° temperature it would certainly be impossible to attain to anything like the theoretical minimum consumption, which left no margin at all of extra carbon for producing the heat required for smelting the ore; and it must be borne in mind that the mere transfer of oxygen from the ore to the carbon was not attended by any evolution of heat, but by an absolute absorption of heat.

Mr. G. Addenbrooke remarked that, in regard to the theoretical minimum consumption of only $7\frac{1}{2}$ cwts. of coke per ton of iron made, they were very far from attaining to any such result in South Staffordshire, and he should be very glad of every nearer approach to it. The consumption of 30 cwts. of coke per ton of iron in the smaller Cleveland furnace of 55 feet height described in the paper was not a greater degree of economy than that already attained in some South Staffordshire works, where the consumption was not much more than 30 cwts. of the raw coal of the district. On account of this use of raw coal, instead of coke or a mixture of coke and coal, there was such an excess of gas given off from the furnaces beyond the utmost requirements for heating purposes, that the necessity of utilising the whole of the waste gas had never been a matter of importance in Staffordshire: when sufficient gas was utilised for all the heating purposes required in connection with the furnaces, there was no occasion to take any trouble about saving the rest of the gas. At his own works in the South Staffordshire district the principle on which he had acted had been to make good iron, as the first requisite, and to utilise the waste gas if practicable; if this could not be done without interfering with the quality of the iron, he considered it preferable to abandon the attempt to utilise the gas. He had found that the gas could be effectually taken off with the furnace top entirely open, by means of a ring of lateral openings round the furnace throat a few feet below

the top (see Proceedings Inst. M.E. 1865 page 235), thus avoiding all trouble as well as the expense and interruption resulting from the use of a charging hopper and bell for closing the top of the furnace: the gas could in this way be so completely taken off that he had frequently walked across the materials in the open top of the furnace whilst driving at the rate of 220 tons of iron per week. Great value was sometimes ascribed to the distribution of materials effected by the use of the charging bell; but with open-topped furnaces there was no difficulty whatever in regulating the distribution of materials exactly as was required; and he thought that by keeping the furnace mouth constantly full up to the top, with successive layers evenly spread, the materials were as well distributed as they could be by any arrangement. In the Cleveland district he knew of a furnace at the Grosmont Iron Works, working on the same open-topped plan as his own furnaces at Darlaston, which was stated to be doing better than any furnace in that district had been known to do previously, on account of means being taken for more accurate levelling of the materials on filling in the charges at the open top of the furnace.

The CHAIRMAN enquired what was the proportion of calcined ironstone and limestone used in the South Staffordshire furnaces consuming 30 cwts. of raw coal per ton of iron made.

Mr. G. ADDENBROOKE replied that at his own furnaces they calculated their yields on the raw coal, ironstone, and limestone; and the proportions employed were about 50 cwts. of raw ironstone and 8 cwts. of limestone per ton of iron made, the weight of minerals and iron being taken at 120 lbs. per cwt.

With regard to the increased height of furnace advocated in the paper for the Cleveland district, there was no doubt that great benefit had been experienced from increasing the height in that district, and also in Shropshire, and in Lancashire at the Wigan Furnaces. He thought this was a question which ought to be considered also in reference to the South Staffordshire furnaces. The objection hitherto urged against such a step had been the friable nature of the soft Staffordshire coal, which it was thought would be incapable of sustaining the crushing weight of a higher column of materials in the furnace. He considered however this

was a mistake, and he believed the weight of the materials in the upper part of the furnace was to a large extent supported by their taking a bearing against the sides of the furnace; just in the same way that, if a parallel glass tube were filled with similar materials, it would be seen that their lateral pressure against the sides of the tube relieved the bottom from much of the weight. If this opinion were found correct, it would give new life to the furnaces in the South Staffordshire district.

Mr. E. A. Cowper quite agreed in the opinion that a considerable proportion of the weight of the materials in a blast furnace was taken by the sides of the furnace, particularly in one of such a shape as the larger of the two furnaces shown in the drawings. This might be exemplified by taking a pipe of $1\frac{1}{2}$ inch diameter and 1 foot length and filling it with sand, when it would be found almost impossible to drive the sand through the pipe by pressure; and if the pipe were placed vertically with the bottom closed by a piston sustained by a spring balance, it would be seen that the weight actually supported by the balance was only a small fraction of the whole weight of the sand in the pipe. Through overlooking this principle of lateral support, it had been usual to consider that the boshes in a blast furnace would have to sustain the whole weight of the superincumbent materials; and he thought the boshes had on this account been sometimes made too flat, where the sides of the furnace might have been trusted to for partially supporting the burden. The occasional occurrence of scaffolding in the working of blast furnaces was indeed a sufficient indication of the support which the sides were capable of affording.

With regard to the economy of coke effected in some of the blast furnaces in the Cleveland district, he considered that much was to be attributed to the very great heat of blast now employed.

Mr. Samuel Lloyd remarked that the height of the blast furnaces in South Staffordshire was only from 45 to 50 feet, and as the plan of taking off the waste gas by closing the furnace top with a charging hopper and bell required a height of 7 or 8 feet to allow sufficient space for lowering the bell in charging, the level of the top of the materials in the furnace would have to be that distance below the filling plates; and it would be a question therefore whether it would

be safe to reduce the height of the materials to that extent, or whether it would not be necessary with that mode of closing the furnace top to raise the furnace 7 or 8 feet, so as not to interfere with the present height of working. At their own furnaces at Wednesbury a vertical tube was inserted in the centre of the furnace mouth, through which the gas was taken off, and the materials were filled in right up to the furnace top in the open annular space surrounding the central tube, so that the full 48 feet height of the furnace was preserved for the height of the materials (see Proceedings Inst. M.E. 1860 page 251).

Mr. COCHRANE observed that in any case of closing the top of a blast furnace by the hopper and bell arrangement, where it was important not to interfere with the existing height of the materials in the furnace, the proper plan would of course be to raise the furnace top sufficiently to allow the requisite additional height for the lowering of the bell in charging. In regard to the question of the hardness or softness of the fuel as affecting the height of furnace that was practicable in any particular district, he thought the breaking up of the material under an increased height of furnace was to be explained, not so much by the crushing weight of the superincumbent mass, as by the severe grinding action to which each separate piece was subjected in rolling over during its descent from the furnace top; this action was of course greater with an increased height of furnace, and it was only on account of the very hard quality of the coke employed in the Cleveland furnaces that it had been practicable to increase their height to the extent now attained in that district.

With respect to the reduction of 110° in the temperature of the escaping gas, and the saving of 14 per cent. in the consumption of coke per ton of iron made, consequent upon the difference of 13,452 cubic feet between the two sizes of blast furnace described in the paper, it should be borne in mind that these results were independent of the absolute quantities of material filled into the furnace per hour, that is the rate of driving of the furnace; for it was found by observation that the temperature of the gas escaping from the top of the furnace remained the same, whether the make were 200 tons per week or 300 tons, although with more perfect thermometers

a small difference would probably be discovered: with a smaller quantity of materials going into the furnace there was less gas produced to heat them, and with more materials going in there was a greater supply of gas for heating them. He therefore considered it was reasonable to assume that a further addition to the capacity of the furnace would be accompanied by a proportionate further reduction in the temperature of the gas together with a proportionate saving of coke. This appeared also to be practically the opinion generally entertained in the Cleveland district, as every one who had originally built furnaces intermediate in size between those shown in the drawings had subsequently gone on to build still larger furnaces, and had found a saving occasioned by the increase of size; and at the present time furnaces were being erected up to 120 feet in height, with the expectation of a further saving of fuel. The only exception to the proportionate reduction in the temperature of the escaping gas would be when the reduction had been carried so far that the temperature of the gas approached more nearly to that of the fresh materials filled into the furnace top, when the absorption of heat would of course become gradually less rapid; and it might not be possible with anything short of an indefinite height of material to get the last portion of heat absorbed from the gas.

Mr. C. W. Siemens did not understand how the temperature of the escaping gas could be independent of the rate of driving of the furnace, unless an excess of heat-absorbing surface had been provided; because with a greater rate of driving, a given extent of surface would then be called upon to absorb a greater quantity of heat in the same time. When the extent of cooling surface of the materials was so proportioned as to reduce the temperature of the escaping gas to a certain degree, short of the ultimate attainable point, only a small further quantity of waste heat would be absorbed by passing a greater quantity of gas over the same amount of surface in the same time, and the consequence would be that the gas would escape hotter; just as, in the case of a steam boiler, a small extent of boiler surface caused a hot chimney. This question however was independent of the chemical advantages that might be obtained by hard driving.

Mr. COCHRANE remarked that with the two sizes of blast furnace described in the paper he had been surprised to find the actual saving of coke effected by the increased capacity of the larger furnace agreed so closely as it did with the theoretical saving which should result from that increase; but it was possible that the ratio of saving might not continue exactly the same when the increase in the capacity of the furnace was carried much further.

Mr. H. J. MARTEN enquired whether it was considered by those who had had experience in the working of blast furnaces both in the Cleveland district and in South Staffordshire, that there would be any advantage in increasing the size of the furnaces in the latter district to anything like the capacity of the larger of the two furnaces described in the paper, containing 20,000 cubic feet; and if so, whether the particular proportions shown in the drawing of that furnace would be considered suitable, or whether a different shape for the boshes and top of the furnace would be preferred. He might mention that at the Lilleshall Iron Works in Shropshire the height of some of the cold-blast furnaces had been already increased from 50 to 70 feet with a saving of 7 or 8 cwts. of coal per ton of iron; the Shropshire coal used in those furnaces was quite as soft and friable as that employed in South Staffordshire, but with the higher furnaces it had been necessary to use also a small proportion of hard coke mixed with the coal, though not so much as to bring up the cost of fuel so mixed with the hard coke to anything like what would counterbalance the saving over the lower furnaces using coal alone. The result therefore showed a decided economy in cost of fuel in the higher furnaces; and the saving from their increased capacity would no doubt be more marked in the event of using hard Derbyshire coal.

Mr. COCHRANE considered that, on account of the friable nature of the coal used in the South Staffordshire blast furnaces, the height of 50 feet was quite sufficient for the furnaces in that district, and he did not think it desirable to go beyond that height; but furnaces of less height he thought might with advantage be raised up to the 50 feet.

Mr. SAMPSON LLOYD remarked that the Ferryhill furnaces in the Cleveland district, 105 feet high and 27½ feet diameter at the boshes,

were working he understood at 16 cwts. of coke per ton of iron made; and he enquired whether this result, in comparison with the consumption of 26 cwts. per ton in the furnace described in the paper, was to be attributed entirely to the increased height and diameter of the larger furnaces.

Mr. COCHRANE replied that in the case of the Ferryhill furnaces the low consumption of 16 cwts. of coke per ton of iron was mainly due to the quality of the ore employed there, the raw ironstone containing more than 40 per cent. of iron, and nearly 50 per cent. he believed in the calcined state; whereas the percentage on which the calculations given in the paper were based was only 40 per cent. of iron in the calcined ore. In the Ferryhill furnaces he considered there must of course be a proportionate saving of fuel from their increased capacity as compared with the larger of the two furnaces described in the paper; and a further source of economy might be the marked improvement effected in the construction of the cast-iron hot-blast stoves in the Cleveland district, some of which supplied the blast regularly at a temperature of 1100°, and thus for some time closely followed in height of results Mr. Cowper's regenerative hot-blast stoves in use at his own works, although the high temperature of 1400° named in the paper had subsequently been obtained from the latter—a temperature unattainable by cast-iron stoves.

Mr. G. ADDENBROOKE enquired what had been the effect of the increased height of blast furnace upon the quality of iron made, as he had understood the result had been an improvement in quality.

Mr. W. LLOYD thought that one reason why blast furnaces of such very large capacity could be worked with so much economy in the Middlesbrough district was the porous character of the materials used there, both coke and ironstone. With a very dense fuel and ironstone, the gas passing up through the furnace could not penetrate the materials to such an extent, and the reduction in temperature of the escaping gas could not be so great as if the same mass of materials were of a porous character. It would therefore be important in building large furnaces to consider the nature of the materials to be worked, whether porous or dense.

Mr. COCHRANE said he had not made any experiments with different kinds of fuel and ironstone, and was not able therefore to

state how far the economy of the large blast furnaces was affected by the nature of the materials, in respect to their dense or porous character. With regard to the effect of the increased height of furnace upon the quality of the iron made in the Cleveland district, he had found that a marked improvement in the quality had been caused.

Mr. L. T. McEwen observed, in reference to the economy of fuel effected by increasing the height of the blast furnace, that an illustration of a similar action was afforded by the regenerative hot-blast stoves, in which the flame heating the stove entered the mass of firebrick forming the regenerator at a temperature of 3000° or upwards, but quitted the regenerator at only 200°; and as the heat of the ascending gas in a blast furnace was absorbed by the materials in the upper part of the furnace in exactly the same way as by the firebrick of the regenerator, he thought any addition to the height or capacity of the furnace must cause more heat to be absorbed from the gas, and thereby produce a corresponding economy of fuel.

Mr. C. W. Siemens thought the illustration suggested of the firebrick regenerator in the hot-blast stoves was not a parallel case, because the area of cooling surface of the firebrick in the regenerator was practically unlimited, on account of the means afforded of reversing the direction of the current through the regenerator as often as desired, whereby the points of maximum and minimum heat might virtually be separated by any distance required.

Mr. L. T. McEwen remarked that in the case of the blast furnace the material forming the regenerator was practically being continually renewed at the same rate at which the furnace was working, by the substitution of fresh cold material at the furnace top.

Mr. C. W. Siemens replied that no means was thereby obtained of taking up a greater quantity of heat from the escaping gas in the blast furnace, because there was only a limited quantity of material, which was heated by a fixed quantity of gas; for although in any particular quarter of an hour it might be possible to fill in more material than corresponded to the average rate of smelting, yet in the course of a week the total quantity of ore put in was exactly the quantity smelted; and for absorbing the extra heat generated in

smelting 1 cwt. of ore at the bottom of the furnace it was not possible by any means whatever to add more than 1 cwt. of fresh ore at the furnace top, with the proportionate quantity of the other materials.

Mr. H. J. MARTEN remarked that it was no doubt the correct view to regard the materials in the upper portion of the blast furnace as acting the part of a regenerator, and thereby extracting the heat from the ascending gas; and this constituted the basis of the saving attending the working of the higher furnaces. The calculations given in the paper however were made upon the assumption that the rate of filling in of fuel in the larger furnace would remain the same per ton of iron made as in the smaller furnace; but it must also be borne in mind that the heat saved in a furnace of larger capacity by the regenerative action of the descending materials brought about a reduction in the rate of fuel charged into the furnace, and a consequent reduction in the quantity of heat generated by the combustion of that fuel at the bottom of the furnace. It therefore appeared to him that by increasing the height of the blast furnace this action and reaction would cause the reduction in the temperature of the escaping gas to take place at a considerably higher rate than the simple ratio of the increase in height and capacity, and that the point of maximum economy would consequently be attained much earlier than was inferred in the paper. With regard to the construction of blast furnaces generally, there were many reasons which led him to the opinion that the tendency of furnaces in the future would be in the direction of becoming entirely boshes; that is, that the stack portion would be dispensed with, and the lines of vertical section of the furnace would approach those of a parabolic funnel, with its small end constituting the hearth.

The CHAIRMAN observed that, with reference to the difference of opinion which appeared to exist on the very important question of the effect of increased capacity upon the economy of a blast furnace, it had been argued on the one hand that, as with similar materials and similar productions of iron per week there could be evolved from a furnace only the same quantity of heat, and there could come into a furnace only the same weight of materials in a

given time, whether the furnace were large or small, it would follow that the true limit to the reduction of temperature must be measured by the capacity of the materials coming into the furnace during a given time to absorb the heat produced in that time; and it was assumed that the capacity of those materials to take up heat from the escaping gas would be completely satisfied, when their temperature had been raised, and that of the gas lowered, to a practical uniformity of say 500°. Under these circumstances it was urged that it was of no use to make the furnace higher, because that step merely added to the quantity of materials present in the furnace, but did not afford the means of putting in any greater amount of new material during the given time, and therefore the temperature of the escaping gas could never be brought down below the limit of 500°. If however, as was represented on the other hand, the new material filled into the furnace was really capable of absorbing more heat from the escaping gas, and failed to do so only because the gas did not come in contact with the material for a sufficient time, then an increase in the height of the furnace would be productive of economy by increasing the time that the new material would be in contact with the gas, and so enabling it to absorb more heat and cool down the gas to a lower temperature at its exit. Whether in the present large furnaces of the Cleveland district the point of equalisation of the temperatures had yet been practically reached, so that no more heat would be taken up by any further increase of height, was an important question: it was one that appeared to him to a considerable extent a matter of calculation, for which data might be procured from comparing the working of the high furnaces erected a few years since with that of the higher furnaces more recently erected. He hoped the subject would be taken up again at a future meeting, and that the further particulars requisite for arriving at a satisfactory conclusion would be furnished.

He proposed a vote of thanks to Mr. Cochrane for his paper, which was passed.

# ON THE FURTHER UTILISATION OF THE WASTE GAS FROM BLAST FURNACES, AND THE ECONOMY OF COKE DUE TO INCREASED CAPACITY OF FURNACE.

By Mr. CHARLES COCHRANE, of Dudley.

(*Supplementary Paper, read at the Meeting on 28th January*, 1869.)

In the previous paper read at the last meeting of the Institution, a calculation was given for ascertaining the maximum limit of size required for a blast furnace in order to save the whole of the remaining heat at present lost in the escaping gas, by cooling the gas down to the temperature of the external atmosphere before it leaves the furnace: the calculation being made for the furnaces working in the Cleveland district, with ironstone containing 40 per cent. of iron. A correction is however required in that calculation, in order to allow for the circumstance that the reduction in the consumption of fuel per ton of iron, consequent upon the economy effected by increased size of furnace, will cause at the same time a corresponding reduction in the quantity of gas evolved per ton of iron made; and consequently, by reducing the proportionate quantity of gas to be cooled, will cause the actual reduction in temperature of the escaping gas to be considerably greater than was obtained in the original calculation; and the result will be that the maximum limit of size of furnace will be sooner arrived at.

It has been seen that a reduction of 110° in temperature of the escaping gas results from the increase of 13,452 cubic feet in capacity of furnace, and is accompanied by a saving of 4·3 cwts. of coke per ton of iron made; and it was assumed that for each further addition of 13,452 cubic feet to the capacity of the present large furnace there

would be a further reduction of 110° in temperature of the escaping gas, together with 4·3 cwts. further saving in consumption of coke per ton of iron. But instead of the 26·5 cwts. of coke per ton of iron that are consumed in the present large furnace of 20,624 cubic feet capacity, the still larger furnace increased to 34,076 cubic feet capacity would have a consumption of only 26·5 − 4·3 = 22·2 cwts. of coke per ton of iron: and consequently a proportionately smaller quantity of gas would pass up through the furnace containing an increased quantity of material for cooling the gas. The reduction of temperature in the escaping gas will therefore be inversely proportionate to the diminished consumption of coke; and the second addition of 13,452 cubic feet to the capacity of the furnace being assumed to reduce the consumption to 22·2 cwts. of coke per ton of iron, the corresponding reduction of temperature in the escaping gas from a furnace of 34,076 cubic feet capacity would consequently be

$$110° \times 2 \times \frac{30·8}{22·2} = 305°$$

Deducting this 305° from 670°, the temperature of the gas escaping from the original small furnace, there will be left only 365° as the probable temperature of the gas escaping from the furnace increased to 34,076 cubic feet capacity.

Similarly in the case of a still larger furnace increased by a third addition of 13,452 cubic feet, assuming that a further saving of 4·3 cwts. of coke per ton of iron would be effected, the consumption of coke would then be 22·2 − 4·3 = 17·9 cwts. per ton of iron; and the reduction in temperature of the escaping gas would consequently be

$$110° \times 3 \times \frac{30·8}{17·9} = 568°$$

This deducted from 670°, the original temperature of the escaping gas, leaves only 102°, or only 32° in excess of 70°, which may be taken as the average temperature of the surrounding atmosphere.

Practically therefore the maximum size of a blast furnace in the Cleveland district would be 7172 cubic feet (the size of the original small furnace) + 3 times 13,452 = 47,528 cubic feet total; and keeping all the proportions of hearth, throat, and boshes, the same as in the present large furnace, this maximum capacity would be obtained with a height of 102 feet and 30 feet diameter at the boshes. Such a furnace should work with 17·9 cwts. of coke per

ton of iron made, taking the ironstone as yielding 40 per cent. of iron, and the blast delivered into the furnace at 1000° temperature. This result is about $10\frac{1}{2}$ cwts. of coke in excess of the theoretical amount of 7·43 cwts. with which a ton of pig iron should be produced, as shown in the previous paper; and it points to the fact that any further economy in fuel must be sought for in other directions than that of increasing the size of blast furnaces beyond the maximum limit above ascertained.

In reference to the working of blast furnaces, the question has arisen whether a variation in the rate of driving of a furnace materially affects the results of its working as to economy of fuel; and the writer is enabled to give some definite information on this point from the results of the actual working of the two furnaces at the Ormesby Iron Works which were described in the previous paper, the smaller one having a capacity of 7172 cubic feet, and the larger one 20,624 cubic feet, as shown in Figs. 6 and 7, Plate 4.

The comparison given in the previous paper of the working of these two furnaces was based upon the total results of a month's working in August last, both under the same circumstances of quality of ore, &c. The average rate of driving during that time was, in the small furnace 60 charges per day of 24 hours, and 53 charges per day in the large furnace, each charge containing 20 cwts. of coke; and in the following month the average was 56 charges per day in the small furnace and 53 in the large one. The average consumption of coke during each of these two months separately was 30·8 and 30·2 cwts. per ton of iron in the small furnace, and 26·5 and 25·8 cwts. in the large furnace: the quality of the iron made in each furnace continuing the same throughout the whole time. The saving in the large furnace, due to the cooling effect of the greater quantity of material contained in it, is therefore 4·3 and 4·4 cwts. of coke per ton of iron during the two months respectively; and this result accordingly shows that the difference in rate of driving did not sensibly affect the economy of fuel.

For the purpose of checking this conclusion by the results of a longer period of working, and a greater variation in rate of driving,

a comparison has also been made between the working of the small furnace over a period of ten months taken two years ago (1866), when its weekly make was only 232 tons of iron, and of the same furnace over another period of eight months during last year (1868), when the rate of driving was increased so that its make was 60 tons per week greater, or 292 tons per week total. The average consumption of coke during the former of these two periods was 30·7 cwts. per ton of iron, and during the latter 30·2 cwts.; showing that, even with this great variation of one fifth in the rate of driving, the comparative economy of fuel is not materially affected. During four months of the latter period the average weekly make was as high as 303 tons; and the average consumption of coke was then 29·7 cwts. per ton of iron, instead of the original rate of 30·7 cwts., the consumption of coke being thus a little reduced with the increased rate of driving.

That the temperature of the escaping gas may be affected to a slight extent by increasing or diminishing the rate of driving beyond certain limits, there can be little question; but the amount of variation has not yet been found sufficient to become material.

The main facts appear to be:—first, that although the rate of driving be increased, the corresponding additional quantity of cooling material filled into the furnace is sufficient to meet the increased production of gas; and on the other hand, if the rate of driving is diminished, less gas is produced for less cooling material charged. Secondly, that the very fact of increasing the rate of driving in a hot-blast furnace (as contradistinguished from a cold-blast furnace, in which the opposite effect would be produced) occasions a proportionate increase in the total amount of chemical action taking place during the same time; and although no more units of heat are developed per lb. of carbon burnt, the temperature is intensified in the neighbourhood of the tuyeres, and the zone of greatest heat does not extend up to so high a level in the furnace: the height of the furnace is thus virtually raised by the more intense heat pervading the lower portion. It may further be remarked that the radiation of heat from the casing of the furnace is constant, whatever the rate of driving, and therefore is less felt upon a larger produce.

It appears therefore to the writer that an increased rate of driving of a furnace does not produce any unfavourable effect on the temperature of the escaping gas; on the contrary, the facts which have been ascertained rather lead to the conclusion that the effect of an increased rate of driving is slightly favourable to the economy of coke, within certain limits of variation in the rate of driving according to each particular size of blast furnace.

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(*Discussion at the Meeting on 28th January*, 1869.)

Mr. I. Lowthian Bell was sure they were all greatly indebted to the author of the paper just read for having brought before the Institution the very important question of the economy of fuel in blast furnaces of increased capacity, which was a subject of particular interest at the present time; and also for having communicated in the paper facts of no ordinary importance in the working of blast furnaces. The subject was one in which he himself felt a great interest, having early taken part in the gradual enlargements that had been made in the size of blast furnaces. In the Cleveland district the furnaces were at first not more than about 45 feet high, but the height was soon increased in those subsequently built to 56 and then to 60 feet; and from the satisfactory results of these enlargements it became at once apparent that it was a matter of the deepest importance to the ironmasters in that district to ascertain how far the working of a furnace might be influenced by a still further addition to its height. From the experience previously obtained, it had appeared to the late Mr. Vaughan and himself

that there was reason to expect a considerable improvement in the working of a furnace by a further addition of 15 feet to its height; and one was therefore erected of 75 feet height and 16 feet diameter at the boshes, having a capacity of 11,985 cubic feet. As soon as this furnace was blown in, he proceeded to note various results of its working, believing as he did at that time that if any advantage did accrue from the increased dimensions it would be explained by the fact that a larger proportion of the heat previously carried off by the escaping gas would now be intercepted and saved by the higher column of materials through which the ascending gas had to pass in the upper part of the furnace. The first step was to ascertain the temperature of the escaping gas, and to compare this with what had been observed at the previous smaller furnaces in the district, having capacities varying from 3,500 to 6,000 cubic feet; and the result of these investigations he had communicated to the British Association in 1863, shortly after the furnace of 75 feet height had been started at Messrs. Bolckow and Vaughan's works. From want of sufficient data at that time however, he was now inclined to think the opinion then formed was not a perfectly correct one; and he had reason to believe, and would endeavour to show, that the economy resulting from increased capacity of blast furnaces was due to some other cause besides the mere interception of heat which was previously lost in the escaping gas. Since that time he had continued the enquiries into the working of blast furnaces of various dimensions; and in consequence of the facilities which had been so readily afforded to him by the rest of the ironmasters, there had rarely been in the Cleveland district a furnace blown in of any increased capacity, without his having had an opportunity of examining the temperature and other matters connected with its working; so that he had now collected data from furnaces extending over a range of capacity from 3,500 to 33,000 cubic feet.

Any subject connected with the saving of the gas evolved from a blast furnace was a matter deserving of investigation; and having seen the working of the double-closed furnace top described in the paper, he believed that it would be found to answer the purpose of saving the portion of gas which had previously been lost at

the times of lowering the charging bell. With charges of 44 cwts. of materials it appeared from the paper that this loss amounted to 6 per cent. of the total gas evolved from the furnace; but at the Clarence Iron Works in the county of Durham his firm had lately blown in a furnace in which about 136 cwts. of materials were charged at each time of lowering the bell. The rate of driving being about the same as given in the paper, the lowerings of the bell and the consequent loss of gas would therefore be reduced in that case to about one third; but he did not mean to imply that even as little as 2 per cent. of the total gas evolved was not quite worth saving by means of the plan now described of doubly closing the furnace top.

Upon the two principal questions treated in the paper—namely, the maximum size of blast furnace for intercepting the whole of the heat at present passing off in the escaping gas, and also the theoretical quantity of coke that would then be sufficient for the reduction of a ton of pig iron—the results of his own experience in the working of blast furnaces led him to conclusions differing considerably from those arrived at in the paper now read. With regard to the size of furnace necessary for abstracting all the heat from the gas evolved, it had been shown in the paper, from actual comparison of a small furnace of 7,172 cubic feet capacity with a large one of 20,624 cubic feet, that the addition of 13,452 cubic feet to the capacity had the effect of absorbing 110° Fahr. of temperature from the escaping gas; and from these figures it had at first been estimated that the capacity of a blast furnace which should absorb all the heat from the gas would have to be 80,546 cubic feet. Allusion had however at the same time been made to the increasing difficulty that arose of establishing an equilibrium of temperature between two bodies, the more nearly they approached each other in temperature; and this appeared to him a most essential question in connection with the subject, and he thought far too little importance had been attached to it. The published information was very imperfect as to the rate at which the transfer of heat took place from a gas to solid materials such as those met with in a blast furnace. The nearest approach to the required data was furnished

by the experiments of MM. Dulong and Petit, who ascertained that a mercurial thermometer, having a temperature of 460° Fahr., lost by radiation 19° in one minute; at 320° it lost only 9°, and at 180° only 3° in one minute. According to these experiments therefore, the rate of transfer of heat diminished so very rapidly as the two bodies more nearly approached each other in temperature, that instead of the maximum size of blast furnace requiring to be reduced from the first estimate of 80,546 cubic feet to the corrected estimate of 47,528 cubic feet, as given in the supplementary paper, he thought it would have been much nearer the truth if the original estimate of 80,546 cubic feet had been doubled, in place of being reduced nearly to one half. An illustration taken from a much higher point in the scale of temperatures and showing the great rapidity of transfer where there was a great difference of temperature between the two bodies, was afforded by observations that he had made upon one of the close-topped blast furnaces at the Clarence Iron Works. Those observations showed that at a depth of 8 feet below the charging plates the temperature of the gas ascending in the furnace was 1200° Fahr., while at the same time it was only 800° in the top of the furnace, although the quantity of materials contained in the furnace top down to the depth of 8 feet was only about 200 cubic feet.

Even in the absence however of an established scale for the rate of cooling of the gas, he believed that the working of the blast furnaces themselves afforded sufficient data to confirm the opinion he had expressed as to the enormous increase in capacity that would be requisite, in order to render available in the blast furnace itself the last residue of heat now carried off in the escaping gas. For the cooling effect produced upon the gas by the materials contained in the larger furnace was really not in proportion to the increased capacity of the larger furnaces as compared with the smaller. Taking the two sizes of furnace described in the paper, it might safely be assumed that the smaller furnace produced 230 tons of iron per week and the larger one 280 tons; and the raw materials being very nearly in the same proportion, it would be found that the total quantity of material passing through the furnace per hour for every thousand

cubic feet was as much as 17·7 cwts. in the smaller furnace, but in the larger furnace only 7·1 cwts. The larger furnace of 20,624 cubic feet capacity was thus not doing in proportion half the work performed by the smaller furnace of 7,172 cubic feet capacity; and the rate of charging the materials being therefore not half as great in proportion to the capacity of the larger furnace, the cooling effect in reducing the temperature of the gas evolved from the furnace evidently fell very far short of being in direct proportion to the increased capacity of the furnace. This conclusion was also confirmed by the observations he had made upon the working of furnaces having a still greater capacity than the larger of the two described in the paper.

Although it might appear an easy matter to ascertain what was the temperature of the gas escaping from a blast furnace, this was really a far more complicated affair than was supposed. The great difficulty was to obtain an instrument by which to register the rapid changes that took place in the temperature. Assuming the pyrometer employed to be correct, as was the case with that of Mr. Siemens, there was nevertheless one defect attending all pyrometers yet constructed, namely the length of time required by the instrument itself to indicate the temperature. He considered that a pyrometer required five minutes to follow any great alteration of temperature; and as he had found, when the temperature of the escaping gas was low enough to be indicated by a delicate mercurial thermometer, that the rise and fall of temperature at the top of a blast furnace was frequently at the rate of 10° Fahr. per minute, it was obvious that, during the time required by the pyrometer to follow any change, considerable alterations might take place in the temperature of the escaping gas, of which no record whatever would be obtained; and for these an approximate allowance was required to be made. In comparing the temperatures of two furnaces it was necessary to consider the quality of the iron that was being run at each; because the higher qualities of iron required a higher temperature for fusion, and it was clear there could not be a greater heat in the hearth without having the temperature thereby raised at the top of the furnace also, though

not fully to the same extent. In a work by M. Vathaire the point of fusion of grey iron was stated to be 260° Fahr. above that of white iron; and in his own observations made in 1863 he found that the temperature of the escaping gas was 105° higher at a furnace making No. 2 iron than at a precisely similar furnace working under the same circumstances but making No. 4 iron.

With the reservation rendered necessary by the defects of pyrometers and by the want of sufficient opportunity for studying all the circumstances connected with the working of blast furnaces, he thought the results of a comparison made between the temperatures of the gas evolved from three blast furnaces of different sizes at the Clarence Iron Works would confirm the belief that a maximum capacity of 47,528 cubic feet would prove utterly insufficient to intercept the remainder of the heat at present carried off by the escaping gas. The observations on these three furnaces were not confined to one or two experiments, but the results were obtained from several observations made at different times. The first furnace was one having a capacity of 6,012 cubic feet, and the average temperature of the escaping gas was 765° Fahr. The next furnace had a capacity of 15,363 cubic feet, and the average temperature of the gas was 650°, being a reduction of 115° in temperature for an increase of 9,351 cubic feet in capacity. The last furnace, only recently blown in, having a capacity of 25,497 cubic feet, only reduced the temperature of the gas to an average of 580°, being only 70° saving of temperature in the gas for an increase of 10,134 cubic feet in the capacity of the furnace. In comparison with the first furnace, the last, although having four times the capacity, did not reduce the temperature of the escaping gas more than 185°.

In considering the value as a combustible of the gas given off from a blast furnace of increased capacity, it appeared from the paper that a diminution of heating effect in the gas evolved from the larger furnace was anticipated, in consequence of the increased proportion of carbonic acid which it was expected would be found in the gas, owing to the larger furnace carrying an increased burden of ironstone per ton of coke. That the proportion of carbonic acid

would be increased he considered probable, but he thought the increase would be found to arise from another cause, as well as that mentioned in the paper; and he was now engaged in a series of analyses in connection with the subject. As bearing upon this question, he had recently made some experiments to determine the difference between the temperature required for carbonic oxide to decompose peroxide of iron, by combining with the oxygen and forming carbonic acid, and the temperature necessary for enabling carbonic acid to take up carbon so as to become converted into carbonic oxide. In a horizontal glass tube was placed a quantity of Cleveland ironstone previously calcined, and heat being applied to the tube by a lamp, a stream of carbonic oxide was passed through it. The temperature had scarcely reached 500° Fahr. when a perceptible change was discovered in the colour of the ironstone, indicating undoubtedly that chemical action was going on. Within a minute or two from the commencement of this change, the gas issuing from the tube was collected, and was found to contain 46 per cent. of carbonic acid mixed with the carbonic oxide, indicating that even at that low temperature decomposition of the ironstone by the carbonic oxide was going on; and soon afterwards the proportion of carbonic acid rose to 96 per cent. The ironstone being then weighed was ascertained to have lost 39 per cent. of the entire oxygen it contained. In order to make sure that the ironstone had really been deprived of its oxygen to so great an extent, it was then treated with dilute hydrochloric acid, and the gas given off was found to burn with the clear blue flame indicating hydrogen, thereby showing that the iron existed in the metallic condition. The next step was to ascertain at what temperature the carbonic acid gas would take up carbon; and for this purpose a quantity of ordinary blast-furnace coke was placed in another similar glass tube and heated in the same way, and a stream of carbonic acid gas was passed through the tube. While the process was going on, samples of the gas issuing from the tube were frequently examined, to ascertain how far the carbonic acid might have become converted into carbonic oxide; but it was not until the German green glass composing the tube failed and was melted that the faintest trace could be perceived of carbonic

oxide; and even at that time he was satisfied not so much as 1-500th part of the gas passing through the heated coke had experienced any change. These experiments led him to believe that carbonic acid did not act at all upon coke at any temperature below 1000° or 1200° Fahr.; but that the ironstone smelted in a blast furnace continued to be reduced by the carbonic oxide at a much lower temperature, probably as low as 600° or even below that point. Hence it appeared to him that the reducing action of the carbonic oxide upon the ore would extend far up into the cooler region of the upper part of the furnace; and that there would consequently be an increased proportion of carbonic acid in the gas given off from the larger furnaces, arising only partially from the increased burden of ironstone per ton of coke, but also partly occasioned by the circumstance of the increased height of furnace affording the opportunity for a greater proportion of the ironstone to be reduced by the action of the carbonic oxide gas, the latter becoming itself converted thereby into carbonic acid, instead of passing off as it did from the smaller furnace in the form of carbonic oxide.

The mode of estimating the value of the heat saved in the larger of the two furnaces described in the paper, by referring to the consumption of coal in the ordinary cast-iron hot-blast stoves, seemed to him somewhat more complicated than was necessary; and the calculation itself appeared to be based upon erroneous data, and therefore leading to a fallacious result. For although it was no doubt true that the cast-iron stoves required $5\frac{1}{2}$ cwts. of coal for heating the 174 cwts. of blast necessary to be supplied into the furnace per ton of iron made, it was also certain that by no means the whole of the heat produced by the combustion of this $5\frac{1}{2}$ cwts. of coal was sent into the furnace in the form of hot blast; nor even was so much heat utilised in the blast as would be developed by the combustion of the more moderate quantity of $4\frac{1}{2}$ cwts. of coal, which had been taken in the paper as the consumption that ought to be sufficient for heating the blast if the coal were economically burnt. For if the loss of heat at the chimney of the cast-iron stoves had been ascertained, as had been done in regard to the gas escaping from the blast-furnace top, and if even a very small allowance had been

made for loss by radiation from the stoves, he believed it would have been found that the heat actually communicated to the hot blast was no more than that developed by the combustion of only about two-thirds of the $5\frac{1}{2}$ cwts. of coal really consumed; and the result would then agree closely with the theoretical 3·32 cwts. of carbon found by calculation to be necessary for heating to 1000° Fahr. the 174 cwts. of blast required per ton of iron made.

The simpler mode of ascertaining what saving of fuel was represented by the lower temperature at which the gas passed off from the larger furnace, appeared to him to be by calculating the difference between the total units of heat escaping from each of the two furnaces, and then converting that difference into the equivalent weight of fuel. This calculation had indeed been attempted in the paper, as a corroboration of the saving of coke actually observed in the larger furnace; but an error had arisen through taking the units of heat developed by the combustion of 1 lb. of carbon into carbonic oxide to be 2880 Fahrenheit units, instead of which the correct figure was 2220 Centigrade units, or about 4000 Fahr. units. Also the specific heat of the mixed gas passing off from the furnace, instead of being the same as that of nitrogen, namely 0·275, as assumed in the paper, amounted to only 0·240 when calculated from the specific heat and relative proportions of its component gases. When these two corrections were made, it would be found that the 218 cwts. of gas passing off at 670° from the smaller of the two furnaces described in the paper represented a consumption of 8·76 cwts. of carbon, while the 189 cwts. of gas escaping at 560° from the larger furnace corresponded to a consumption of 6·36 cwts. of carbon; and therefore the theoretical saving of fuel in the larger furnace, consequent upon the smaller volume of gas escaping and the lower temperature at which it passed off, amounted to 2·40 cwts. of coke per ton of iron made.

The actual saving of coke in the larger of the two furnaces described in the paper was given as 4·30 cwts. of coke per ton of iron made, in comparison with the smaller furnace of only 7172 cubic feet capacity, and he considered this result was not at all overstated, but was amply borne out by the working of other large

furnaces in the Cleveland district. As however it appeared that out of this saving only 2·40 cwts. could be accounted for by the heat abstracted from the escaping gas, the question had yet to be considered, to what other source was the undoubted economy of the large furnaces to be attributed. A very small part of the difference between the two figures just given would arise from the circumstance that the coke used in the Cleveland blast furnaces contained from 5 to 10 per cent. of ash, and also that the pig iron produced was of course not absolutely pure iron; but the result was not materially affected by these distinctions, and he was therefore satisfied to follow the assumption adopted for simplicity in the paper, taking the coke as pure carbon and the pig iron as pure iron. The question under consideration received a satisfactory solution he thought from the facts established by the experiments previously referred to, respecting the temperature at which the carbonic oxide and carbonic acid gases in a blast furnace would act upon the materials in the furnace. In the old type of blast furnaces in the Cleveland district, and probably in most other localities, he thought it likely that the height had just about reached that point where all action of the carbonic acid upon the coke ceased, on account of the temperature at the furnace top being then too low to admit of the carbonic acid absorbing carbon from the coke. But at that height the point would not have been reached where all beneficial action resulting from the reduction of the ironstone by the carbonic oxide would terminate; and there was therefore evidently something to be gained in this respect by raising the height of the blast furnaces, until the gas escaping from the furnace should be reduced to the temperature below which no further action of the carbonic oxide on the ironstone would take place. This limit however, practically speaking, would in his own opinion be reached with a size of blast furnace far below the present large Cleveland furnaces of 20,000 to 30,000 cubic feet capacity, and might perhaps even be arrived at with not more than 15,000 cubic feet capacity. Whatever the size of furnace might be at which the reducing action of the carbonic oxide terminated, it was at any rate clear that in going beyond that size this action could no longer by any possibility be a source of any further economy; and the only

remaining way in which a further economy could be derived from a still higher furnace would be by the interception of a small additional quantity of heat from the escaping gas. As however it had just been seen that, even in the case of a furnace of 20,624 cubic feet capacity, the actual saving of 4·30 cwts. of coke per ton of iron could only be accounted for to the extent of 2·40 cwts. by the heat saved from the escaping gas, he was led to the conclusion that a further increase in the capacity of the furnace would be attended with a very much smaller proportionate saving of coke; and also that, for abstracting a still further portion of heat from the escaping gas, the increase in the capacity of furnace would have to go on at a much greater rate than had been supposed in the paper, while the complete interception of all the heat would hardly be effected with anything short of an infinite capacity of furnace. These opinions were fully confirmed by the results observed at the furnaces at the Clarence Iron Works, the capacities of which ranged from 6,012 cubic feet in the oldest furnace at the works to 25,497 cubic feet in the large one recently blown in; and on comparing the intermediate furnaces of 11,578 and 15,363 cubic feet capacity with the large one of 25,497 cubic feet, and also with a still larger furnace of 29,000 cubic feet at a neighbouring works, he had found that, as far as the temperature of the escaping gas was concerned, the increased capacity of furnace was not attended with anything like the reduction of temperature in the escaping gas that had been calculated in the paper for such increase in the size of furnace.

One other point raised in the paper which he wished to remark upon was the minimum consumption of coke that would theoretically be sufficient for smelting a ton of iron, supposing that it were possible to prevent any portion of the heat being carried off from the blast furnace by the escaping gas. This minimum consumption had been given in the paper at 7·43 cwts. of coke per ton of iron, that is 6·43 cwts. for reducing the ironstone and 1 cwt. for carbonising the iron, regarding the coke as pure carbon and the iron at the moment of reduction as pure iron. There was however a serious error involved in assuming this consumption of 7·43 cwts. of coke to be the whole quantity necessary for smelting one ton of iron; for

although it was true that 6·43 cwts. was the correct chemical equivalent of carbon required for merely reducing a ton of iron to the metallic state from the state of peroxide in which it existed in the ore, no provision had been made for the generation of the heat necessary for carrying on the operations that had to be performed in the blast furnace. This heat was required for three distinct purposes: in the first place, heat was necessary for generating the carbonic oxide gas and raising the temperature of this gas and of the peroxide of iron to the point at which chemical action would take place; a second demand for heat arose from the refrigeration which accompanied the action of the carbonic oxide upon the ore; and lastly, heat was required for melting the iron and cinder in the first instance and preserving their fluidity in the hearth, so as to allow of bringing them out of the furnace in the usual way by tapping. The theoretical quantity of coke necessary to meet all these requirements in the actual smelting of iron in blast furnaces had already been carefully calculated by several foreign writers in the case of certain descriptions of ore; and without having had an opportunity of making any experiments upon the difference between the fusibility of the iron and cinder in the Cleveland blast furnaces and in the furnaces to which those calculations applied, he had endeavoured to convert the results of the calculations into an approximate estimate which should be roughly applicable to the peculiar qualities of the Cleveland ironstone, and to the greatly increased quantity of cinder occurring in the Cleveland blast furnaces as compared with those in other districts. For melting the iron itself and keeping it fluid in the hearth till the time of tapping the furnace, he considered the quantity of coke or carbon required in the Cleveland furnaces might be taken at 2·70 cwts. per ton of pig iron made; and for the same purpose 4·50 cwts. would be necessary in respect to the cinder. Then for the heat carried off by the escaping gas, it had already been shown that in the furnace of 20,624 cubic feet capacity this loss was equivalent to 6·36 cwts. of coke per ton of iron; and lastly, the heat rendered latent by the chemical action consequent upon the carbonic oxide reducing the ore, including the 6·43 cwts. of carbon required for

combining with the oxygen in the ore, would probably be represented by about 9 cwts. of coke altogether, after deducting the heat carried into the furnace by the hot blast. The estimate would therefore stand as follows for the minimum quantity of coke or carbon theoretically required for the production of one ton of pig iron in one of the present large Cleveland blast furnaces having about 20,000 cubic feet capacity:—

| | Cwts. |
|---|---|
| Carbonisation of the melted iron ... ... ... ... | 1·00 |
| Melting the iron, and keeping it melted in the hearth ... | 2·70 |
| Ditto as regards the cinder ... ... ... ... ... | 4·50 |
| Heat carried off by the escaping gas ... ... ... ... | 6·36 |
| Heat rendered latent, including the 6·43 cwts. of carbon combining with the oxygen in the ore, say altogether... | 9·00 |
| Total ... ... ... | 23·56 cwts. |

This minimum consumption of 23·56 cwts. of coke per ton of iron made he wished particularly to be viewed as nothing more than an approximate estimate, intended as an illustration of the essential requirements for smelting iron in blast furnaces; and even if it were possible to save all the heat from the escaping gas, the minimum consumption would only be reduced thereby to the extent of 6·36 cwts., bringing it down to 17·20 cwts. of coke per ton of iron. Any further important diminution in the consumption of coke below this amount he believed to be an impossibility, with calcined ironstone yielding 40 per cent. of iron and with blast heated to 1000° Fahr., so long as the smelting of iron continued to be carried on according to the system at present pursued in all blast furnaces, where the presence of imperfectly burnt carbon in the form of a constantly ascending current of hot carbonic oxide was indispensable to the reduction of the ore. If indeed there had been any means by which the whole of the carbon could be perfectly burnt into carbonic acid in the furnace, it might have been possible not only to bring down the consumption of coke to $7\frac{1}{2}$ cwts., but even to surpass that degree of economy; because the heat developed by the combustion of carbon into carbonic acid was in the proportion of 7900 to 2220 as compared with its combustion only into carbonic oxide. He had

himself made an attempt some time ago to carry this theory into practice at their own works, by endeavouring to ignite the carbonic oxide contained in the escaping gas at the furnace mouth, but in such a manner as not to allow the carbonic acid thereby produced to waste the coke in the furnace top by again absorbing a further proportion of carbon; the object being then to utilise this ignited gas for heating the ironstone and limestone before they descended into the furnace. Unfortunately however there were found to be difficulties connected with the practical application of the plan, which though perhaps good in theory was so unsatisfactory in practice that it had to be abandoned.

In conclusion he thought it desirable to point out that all calculations in connection with the working and economy of blast furnaces were attended with some little difficulty in the present state of scientific enquiry regarding the specific heat of the various materials and gases that had to be dealt with. Although much had been done already in respect to this subject, much still remained to be done; and in consulting the works of different writers, there was some difficulty in deciding what set of figures should be adopted. He had himself made use of those derived from the investigations of Regnault, the earlier researches of Favre and Silbermann having undergone some material modifications by subsequent examination. Some discrepancies were therefore to be anticipated between the results arrived at by the calculations of different persons; but in the main he believed the views which he had advanced would be fully borne out by future investigations—namely, that 47,000 cubic feet capacity of blast furnace would fall far short of abstracting all the heat from the escaping gas, and that the consumption of coke in the blast furnace could not by any means be brought down to anything like $7\frac{1}{2}$ cwts. per ton of iron made.

Mr. C. W. Siemens remarked that at the previous meeting, while appreciating the value of the facts brought forwards in the paper then read, he had been unable to agree with the conclusion arrived at as to the quantity of coke that should be sufficient for smelting a ton of iron in a blast furnace having a capacity carried to the

ultimate limits then indicated. The $7\frac{1}{2}$ cwts. of coke per ton of iron, which had been originally named as the theoretical minimum consumption, represented no more than the carbon necessary for combining chemically with the peroxide of iron or calcined ore, and for carbonising the reduced metal so as to bring it into the state of ordinary pig iron; and the idea that it would be theoretically possible, by any increase in the capacity of the blast furnace, to bring down the consumption of coke to that amount, arose from the error of taking a simple arithmetical progression to represent the saving of coke consequent upon successive additions to the size of the furnace. In the supplementary paper now read however, an amended calculation had been offered, by taking into account the reduced capital, that is the reduced quantity of coke in the larger furnaces, upon which the percentage of saving had to be estimated; so that the same percentage of saving, out of a total consumption which was diminished by each successive addition to the capacity of the furnace, represented a less and less absolute saving as the size of the furnace was increased. In this way, considering only the question of abstracting the heat from the escaping gas, the result now arrived at had been that 17·9 cwts. of coke per ton of iron was the limit of minimum consumption that could be attained by simply adding to the height of the furnace. No account however had been taken of the chemical work that had to be constantly performed within the blast furnace; and moreover the additional quantity of heat that could be taken up from the gas by merely adding more material in the furnace top would be found, he considered, to be a very small amount. For although he had shown that, by means of the regenerative system, with a quantity of cooling material relatively very much smaller than was contained in a blast-furnace top, it was quite practicable to take up the heat from the outgoing current down to within 20° or 30° of the incoming draught, yet this was only the case so long as the two opposite currents were equal in the amount of their total capacity for heat; but if the current passing in one direction through the regenerator had a different total capacity for heat from that passing in the opposite direction, then whatever extent was given to the cooling material or regenerator, equilibrium

would never be established, and it would not be possible to cool down the escaping current to the temperature of the entering draught; or applying this argument to the case of the blast furnace, it would not be possible to cool down the escaping gas to the temperature at which the fresh materials were charged into the furnace, owing to the inferior total capacity for heat of the latter.

With regard to the amount of chemical work which was required to be performed in a blast furnace for smelting a ton of iron, he had made a calculation, the results of which it might be interesting to compare with those that had been arrived at by adapting to the Cleveland furnaces the investigations of the foreign writers referred to, whose researches upon the subject he had not previously been acquainted with. In the case of Cleveland ironstone containing 40 per cent. of metallic iron in the calcined ore, the iron being in the state of peroxide had 17 per cent. of oxygen combined with it, and the remaining 43 per cent. of the ore would be silica. To fuse this 43 per cent. of silica, which was equal to $21\frac{1}{2}$ cwts. per ton of iron made, 7 cwts. of calcined limestone would theoretically be required, but in reality he believed 8 or 9 cwts. of limestone was the quantity generally added in the Cleveland district; these would take up about $2\frac{1}{2}$ per cent. of iron, giving a total of about 31 cwts. of cinder per ton of iron made. The 17 per cent. of oxygen combined with the 40 per cent. of iron in the ore was equivalent to 8·50 cwts. of oxygen per ton of iron, and this would require 5·31 cwts. of carbon to produce the mixture of 4-5ths carbonic oxide and 1-5th carbonic acid which he believed actually resulted from the chemical reactions in the furnace; for although it had been calculated in the paper that the proportions in which these two gases passed off at the furnace top were about 2-3rds carbonic oxide to 1-3rd carbonic acid, he thought the difference should be allowed for the amount of carbonic acid evolved from the limestone, and that there would therefore be no material error in assuming the result of the combustion to be 4-5ths carbonic oxide and 1-5th carbonic acid.

The heat necessary to be produced in the blast furnace was therefore that required for performing the three distinct operations of melting the iron itself, melting the cinder accompanying the iron,

and generating into a gaseous form the fixed oxygen in the ore and the fixed carbon in the coke, so as to allow of their chemical combination taking place. Considering first the heat required for melting the iron—taking the total heat developed in forming carbonic oxide as 4000 Fahr. units, and in forming carbonic acid 14,000 units—the combustion of 1 lb. of carbon into the mixture of 4-5ths carbonic oxide and 1-5th carbonic acid would develop 6000 Fahr. units of heat; and therefore—taking the specific heat of iron at 0·12 in comparison with water, and assuming the temperature to which the melted metal was heated (including its latent heat) to amount to 4000° Fahr.—it would be found that to melt 1 ton of iron required $\frac{20 \times 4000 \times 0{\cdot}12}{6000} = 1{\cdot}60$ cwts. of carbon. This estimate was evidently on the safe side, as no account was taken in it of the further heat necessary for keeping the iron melted in the hearth till casting time, which would have raised the quantity of carbon nearer to the estimate of 2·70 cwts. given by Mr. Bell. The 1·60 cwts. received a satisfactory confirmation from actual results which he had obtained in the working of cupolas, showing that the calculation was substantially correct. Next with regard to the cinder, taking its specific heat at 0·20, which he believed was below the mark, and assuming the total heat for melting it to be the same as that for iron, namely 4000° Fahr., it would be found that the melting of 31 cwts. of cinder per ton of iron made would require $\frac{31 \times 4000 \times 0{\cdot}20}{6000} = 4{\cdot}13$ cwts. of carbon. In reference to the third supply of heat required in the blast furnace—for transforming into a gaseous state the fixed oxygen in the ore and the fixed carbon in the coke—it must not be overlooked that in the combination of carbon with oxygen heat was only evolved in consequence of a reduction of volume occurring, and in proportion to the extent of that reduction of volume. But this could only take place when both bodies were already in a gaseous state; and accordingly by the combination of solid carbon with gaseous oxygen in the proportion of one equivalent of each, producing carbonic oxide, the amount of sensible heat evolved (4000 units) was less than half of that (10,000 units) which was further developed when a second equivalent of oxygen entered into combination with

the gaseous carbonic oxide so as to form carbonic acid; because more than half of the total heat developed in the formation of the carbonic oxide (6000 out of 10,000 units) was rendered latent by the solid carbon having first to be volatilised before it could combine with the oxygen. The absorption of latent heat was necessarily still greater when the fixed oxygen in the ore had to be made to enter into combination with the fixed carbon in the coke, because a supply of heat had first to be absorbed sufficient for volatilising both the fixed oxygen and the solid carbon; and he had found practically that, where a mixture of ore and carbon was exposed in a close retort to the heat of a furnace, it was necessary to supply a large amount of heat in order to bring about a combination of the elements. In the combination of the 8·50 cwts. of oxygen of the ore in the blast furnace with the 5·31 cwts. of carbon of the fuel, two processes of opposite effect had to take place: on the one hand, the combustion of the carbon into the final mixture of 4-5ths carbonic oxide and 1-5th carbonic acid, developing 6000 Fahr. units of heat per lb. of carbon, would give a total of $5{\cdot}31 \times 112 \times 6000 = 3{,}568{,}320$ units of heat developed; but on the other hand, the volatilisation and separation from the iron of the fixed oxygen of the ore required the absorption as latent heat of he believed not less than 6000 Fahr. units of heat per lb. of oxygen, and the total absorption of heat thus occasioned would amount to $8{\cdot}50 \times 112 \times 6000 = 5{,}712{,}000$ units of heat absorbed. The difference 2,143,680 units, being an excess of heat absorbed, required therefore to be compensated by an extra consumption of $\frac{2{,}143{,}680}{6000} = 357$ lbs. or 3·19 cwts. of carbon.

These three amounts added together gave $1{\cdot}60+4{\cdot}13+3{\cdot}19=8{\cdot}92$ cwts. of carbon, to which had to be added the 7·43 cwts. required for chemical combination with the oxygen in the ore and for carbonising the pig metal, making 16·35 cwts. of pure carbon. A further addition was required of 10 per cent. or 1·63 cwts. for ashes and water in the coke actually employed in the blast furnaces; and also another 10 per cent. or 1·63 cwts. for effecting the calcination of the limestone and completing that of the ore, and to allow for vaporising the moisture in the materials and for loss

by radiation. The total amount was thus brought up to 19·61 cwts. as the theoretical minimum consumption of coke necessary for the smelting of one ton of iron. The complete consumption was therefore as follows:—

| | Cwts. | |
|---|---|---|
| Melting the iron . . . . . | 1·60 | |
| Melting the cinder . . . . . | 4·13 | |
| Heat rendered latent by reduction of the ore . . | 3·19 | |
| Carbon for combining with oxygen in ore and for carbonising pig metal . . . . | 7·43 | |
| | | 16·35 |
| Ashes and water in the coke, 10 per cent. . . . | | 1·63 |
| Calcining the limestone, &c., 10 per cent. . . . | | 1·63 |
| Total quantity of coke required . . . | | 19·61 cwts. |

In this calculation he had left out of consideration on the one hand the heat that was carried off from the furnace by the escaping gas, and on the other hand the heat brought into the furnace by the hot blast entering at 1000° Fahr.; but on comparing these two quantities of heat it would be found that they balanced each other very nearly indeed. For the 8·92 cwts. of carbon made up by the first three items in the foregoing estimate would require, in order to produce blast-furnace gas consisting of 4-5ths carbonic oxide and 1-5th carbonic acid, 14·27 cwts. of oxygen, which would be contained in 62·04 cwts. of atmospheric air entering as hot blast; while on the other hand the gas escaping at the furnace top would contain the whole of these 8·92 cwts. of carbon and 62·04 cwts. of air, together with the 8·50 cwts. of oxygen existing in the ore and the 5·31 cwts. of carbon supplied into the furnace to combine with it, making altogether 84·77 cwts. of gas, to which had to be added about 10 per cent. or 8·47 cwts. of carbonic acid and vapour of water generated from the limestone and other materials, thus making up a total weight of 93·24 cwts. of gas escaping from the furnace top, in the form of carbonic oxide, carbonic acid, and nitrogen mixed together. Assuming the temperature of this escaping gas to be 600° Fahr. and the specific heat of the mixture to be the same as that of air or 0·267, the total quantity of heat thus carried off from the furnace would be $93{\cdot}24 \times 112 \times 600 \times 0{\cdot}267 = 1{,}672{,}949$ units of heat per ton

of iron made; and at the same time the heat brought into the furnace by the 62·04 cwts. of hot blast at 1000° Fahr. would be $62{\cdot}04 \times 112 \times 1000 \times 0{\cdot}267 = 1{,}855{,}244$ units of heat, leaving a small excess of 182,295 units of heat brought in by the blast per ton of iron made, which was probably not more than would cover the loss of heat by radiation from the furnace.

The actual work done in one of the Cleveland blast furnaces represented therefore a consumption of between 19 and 20 cwts. of coke per ton of iron made, supposing the ironstone to contain only 40 per cent. of iron when calcined, and the blast to be delivered into the furnace at a temperature not exceeding 1000°; and under these conditions he believed no blast furnace could be constructed to work with less than that quantity of coke, although with richer ores and higher temperatures of blast there would of course be a considerable margin for further economy in consumption of coke. Practically speaking he thought that 22 cwts. of coke per ton of iron made would be the best result that would be obtained under these circumstances; and this would be independent of the capacity of the furnace, which might be increased indefinitely without improving upon this estimated minimum consumption.

Mr. F. J. Bramwell remarked that in the paper which had been read it appeared to have been considered that the essential condition for abstracting the remainder of the heat from the escaping gas was an increase in the cubic contents of the furnace; but he thought this was not a complete view of the question, and that other considerations were involved in it, the nature of which might be exemplified by the following simple illustration. Supposing there were a vertical endless band, like an elevator, carrying a series of sponges placed at equal intervals, and travelling downwards in front of a perforated casing containing water, so that the descending sponges should wipe off and absorb the water oozing from the perforations—and supposing the object were that the water so oozing should be wholly taken up by the sponges, without any of it running to waste: then it was clear that, if the height of the casing were very short considered in relation to the speed at which the

sponges travelled, it was possible that by the time the sponges got to the bottom of the casing they might not have become as wet as they could have become if further time had been given. That would be an instance in which more water was not taken up by the sponges because they were not in contact with the water for a sufficient length of time to become saturated; and in such a case therefore it would be possible by increasing the height of the casing to get more water taken up by the sponges travelling at the same speed as previously. But supposing the height of the water casing had now been increased to just such a length that the descending sponges became each of them saturated by the time it arrived at the bottom of the casing, and supposing it were still required to take up an increased supply of water from the perforated casing, it would obviously be of no use to increase the height of the casing any further, with the sponges running at the same speed, because being already saturated they would not be able to take up any more water, whatever length of wet surface they passed over. If however the speed of driving the sponges were now increased, so as to bring a greater number of sponges in contact with the water casing in a given time, the greater quantity of water might be as completely taken up by the sponges running at the higher speed as the smaller quantity had previously been by the same sponges driven at the lower speed. In applying this illustration to the case of blast furnaces,—the length of the perforated water casing representing the height of the furnace, the water supply representing the heat to be abstracted from the ascending gas, and the series of descending sponges representing the fresh materials coming in at the furnace top—it would be seen that, as soon as such a height of furnace had been reached that there had been time for the materials to absorb all the heat they were capable of taking up, any further increase in the height of the furnace would do no good towards effecting any greater absorption of heat, because the additional height would not add anything to the incoming material, but only to the capital stock of material contained in the furnace, which was already as hot as it could be.

Mr. COCHRANE said he had been greatly interested in listening to the very valuable information which had been elicited in the discussion, and the important facts that had been communicated respecting the working of the large blast furnaces in the Cleveland district. With regard to the main fact upon which his own calculations respecting the economy of fuel in larger furnaces had been based, he was glad to be able to state that the saving in the larger over the smaller of the two furnaces described in the paper, which had been given as respectively 4·30 and 4·40 cwts. of coke per ton of iron during the months of August and September last, was fully confirmed by the working of the same two furnaces during the two following months: in October, when the conditions under which the two furnaces worked in regard to blast were so nearly similar that over the whole month the average difference between them in temperature of blast was only 10°, the saving of coke in the larger furnace had been 4·24 cwts. per ton of iron made; and in November, with a difference of only 30° or 40° in temperature of blast, the saving was 4·58 cwts. of coke, the average temperature of blast in each month being the same as stated in the paper, namely about 1000° Fahr.

The saving of gas to be effected by the plan of doubly closing the furnace top would of course depend upon the size of the charges and the consequent number of times per day that the charging bell had to be lowered; so that with charges three times as large as those referred to in the paper, the saving would be reduced from 6 per cent. to 2 per cent. of the whole gas evolved from the furnace. The difference between pure carbon and the coke used in blast furnaces had purposely been omitted in the calculations given in the paper, for the sake of avoiding complication; but it was easy, when any result had been arrived at on the supposition of employing pure carbon, to correct the calculation for coke by adding the proper proportion for ash and moisture. As regarded the increasing difficulty of establishing an equilibrium of temperature between two bodies, the more nearly they approached each other in temperature, he had alluded to this in the paper as a consideration which might affect the question of the maximum size of furnace, but

had not attempted to take it into account in the calculations, owing to the want of any sufficient data upon the subject. It was quite possible indeed that this difficulty would be so great as to necessitate an infinite capacity of furnace in order to abstract all the heat from the escaping gas; but having arrived at a capacity of 80,000 cubic feet as necessary for the purpose even without taking that difficulty into account, he thought he had gone far enough to render it apparent that serious engineering difficulties would be met with in increasing the size of the furnaces, long before a height could be reached at which all the heat would be absorbed, even supposing the saving of heat from the gas were to go on at the same rate as in the present large furnaces.

The difficulty that had been alluded to of getting a suitable pyrometer for measuring the temperatures of the escaping gas was one which he had also experienced; and he agreed in considering Mr. Siemens's pyrometer the most perfect one that had been made, the principle of it consisting in exposing a small ball of copper to the heat required to be measured, and then immersing this heated ball in a definite quantity of water, and measuring the rise of temperature thereby caused in the water. Even this instrument however was subject to errors, arising from the difficulty of obtaining always exactly the same kind of copper for the standard measuring ball that had to be heated; he had himself met this difficulty by procuring in the first instance a bar of the same copper that the original ball was made of, so as to ensure having as nearly as possible the same quality of metal in the new ball, whenever the original one had to be renewed. In order to avoid the other objection that had been pointed out, arising from the copper ball requiring as much as five minutes to register a change of temperature, during which time changes of several degrees of temperature might occur in a blast furnace without being recorded, he had employed one of Gauntlett's pyrometers for measuring the temperatures, the principle of the instrument being to show the difference between the expansion of two metals at the temperature to be measured; an iron rod was inserted loosely into a brass tube about 1 inch in diameter and 4 or 5 feet long, and the two being fixed together at one end the difference of their

expansion was shown magnified on a dial at the other end. This pyrometer was therefore quicker in its indications on account of being in continuous action; and he had taken the precaution to check its accuracy by careful comparison with the Siemens pyrometer before and after the experiments.

The quality of the iron made by a blast furnace was certainly a matter that had to be taken into consideration, in estimating the economy of fuel in the furnace, on account of the extra quantity of coke required for making No. 1 iron as compared with the lower qualities down to white iron; and the reason no reference had been made to this point in the paper was that the average quality of iron made by the two furnaces during the time of comparing their working had been so nearly the same, that it had not been thought necessary to introduce any correction on that account in the results observed. The average of the actual qualities made during the month of August last had been 3·74 at the smaller furnace and 3·48 at the larger. As regarded the quantity of heat developed by the combustion of carbon into carbonic oxide and into carbonic acid, there seemed to have been some error in the figures given in the paper; and consequently, instead of four times the heat being developed by the combustion of carbon into carbonic acid as compared with carbonic oxide, the correct proportion was about $3\frac{1}{2}$ times.

In reference to the supply of heat requisite for getting the iron and slag out of the furnace, he had not included this in estimating the minimum consumption of coke necessary inside the furnace, believing that it would be found practicable, and at the same time far more advantageous, that this quantity of heat should be poured into the furnace by the hot blast, by raising the temperature of the blast to a sufficiently high point for the purpose, which he thought there would be means of accomplishing ultimately. By saving still more heat than at present from the escaping gas and increasing the temperature of the blast, he was inclined to believe, notwithstanding the calculations which had been offered, that a minimum consumption of about 13 cwts. of coke per ton of iron would ultimately be found practicable in the Cleveland blast furnaces; and he should continue to aim at that amount as a limit, until further experience should

prove it impossible. The allowance for waste of heat in the quantity of coal burnt in the cast-iron stoves for heating the blast, he was prepared to admit might be understated in the paper; and it was well known that they were very far from economical in consumption of fuel. He considered they were greatly indebted to Mr. Bell for the valuable data he had furnished from his own very extensive observations on the working of the Cleveland blast furnaces; and he noticed that the remarks which had been made tended to the same conclusion in one respect as his own, namely, that in the larger furnaces the absolute saving to be effected by the increase of capacity would be found continually to diminish in amount as the size was further extended.

Mr. W. Cochrane enquired what was the diameter of the charging bell used at the blast furnaces where the materials were charged in quantities of 136 cwts. at a time.

Mr. I. L. Bell replied that the charging bell used at the Clarence Iron Works for the charges of 136 cwts. was 11 feet diameter, and after each time of lowering, the joint was sealed all round the circumference in the usual way, by throwing in a little mine dust; practically therefore the leakage at the joint was unimportant.

With regard to the idea of reducing the consumption of coke inside the blast furnace by employing blast at a higher temperature than 1000°, his own calculations had been made upon the use of blast at 1000° as the temperature assumed in the paper; and with that temperature of blast he had shown that it would not be possible even theoretically to reduce the consumption of coke so low as $7\frac{1}{2}$ cwts. per ton of iron made. This conclusion he considered would not be modified by raising the temperature of the blast, because that step would only be equivalent to introducing so much more fuel at the tuyeres in the shape of hot blast, instead of charging it in as coke at the furnace top; and the total quantity of heat necessary to be generated in one way or the other would not be reduced.

Mr. F. J. Bramwell remarked that the proportionate yield of the larger blast furnaces seemed very inconsiderable in comparison

with that of the smaller, as it appeared that in the larger of the two furnaces described in the paper the quantity of materials passing through per hour for each thousand cubic feet capacity was not so much as one half of that in the smaller furnace, while the cost of the larger furnaces must evidently be very great; and he enquired whether the actual economy effected by the increased size of furnace was found sufficient to give any considerable profit upon the larger outlay required for structures of such magnitude.

Mr. I. L. Bell replied that the cost of the larger furnaces was certainly very great, and instead of increasing simply in proportion to the size of the furnace he believed the cost was really much greater. But though the outlay in the first instance was so great, there was then no further charge to be met beyond interest on capital, which on an outlay of £10,000 would not be more than £500 per annum; whereas a furnace of that cost would make 400 or 500 tons of iron per week, and upon this amount the saving given in the paper of 4 cwts. of coke per ton of iron would evidently yield a very fair profit upon a year's working, after deducting the payment of interest on capital.

Mr. G. Addenbrooke remarked that there was no doubt a limit, as had been pointed out in the illustration given by Mr. Bramwell, at which the materials charged into the blast-furnace top would have become saturated with heat, and consequently unable to take up any more from the escaping gas. In the large Cleveland furnaces he thought this limit must now have been closely approached, if not indeed already reached. In the South Staffordshire district however he was satisfied that the present largest furnaces of only 50 to 55 feet height were very insufficient for abstracting from the escaping gas all the heat that it was possible to save. With regard to economy of fuel, a theoretical consumption so low as only $7\frac{1}{2}$ cwts. of coke per ton of iron in the Cleveland furnaces had naturally been looked upon with some alarm in other districts; but in comparison with the actual consumption of $26\frac{1}{2}$ cwts. of coke in the larger of the two furnaces described in the paper, the 30 cwts. of raw coal required in the South Staffordshire furnaces for the

same make showed as high a degree of economy; this was the actual consumption of coal per ton of iron made at his own works at Darlaston, and the quantities of the other materials were 50 cwts. of raw ironstone or 33 cwts. of calcined ore, and 8 cwts. of limestone, the calcined ore containing about 53 per cent. of iron.

With regard to the plan of doubly closing the furnace top for taking off the gas, he had previously referred to the mode of taking off the gas from open-topped furnaces as carried out most successfully at his own works at Darlaston, and at several other works in Staffordshire and in other districts; and at the Grosmont Iron Works in the Cleveland district, where the same plan had been adopted, the yield obtained from the furnaces was quite as good as from the other furnaces in that district closed by a bell. At the Grosmont furnaces the yield had at first been bad, in consequence of the throat of the furnace being too wide, and the holes for taking off the gas round the neck of the furnace too high comparatively; the depth of the holes below the top of the materials was much less than the semidiameter of the furnace throat, allowing the gas to be wasted by escaping through the materials in the centre. This defect had been got over and the waste of gas prevented by simply raking the materials level at each charge, and thereby preventing the gas from escaping through the centre before it could be drawn off at the sides. It was considered that the plan of raking the charges at the open top of the furnace gave a better distribution of the materials than was obtained with the closed top and bell. At his own furnaces at Darlaston there was no trouble of raking the materials at the furnace top to prevent the gas escaping, as the gas apertures were at a depth of 4 feet below the top, the diameter of the throat having been reduced to 8 ft. 6 ins.; and except under the circumstances of an unusually large quantity of gas being evolved in the furnace, the whole was taken off so completely that he had frequently walked across the materials in the open top of the furnace while driving at the rate of 220 tons of iron per week. Instead therefore of adopting the doubly closed furnace top for effecting a further saving, he considered it would be more advantageous if the

additional height of furnace required for that arrangement were to be made available by the open-topped plan for adding to the height of the materials in the furnace top and thereby taking up more heat from the gas.

The plenum of pressure under which the gas was supplied from a close-topped furnace appeared to him to involve objections as compared with the plan of drawing off the gas by suction from an open-topped furnace by the draught of a lofty chimney. With the latter method there was no risk either of "gassing" the men at the furnace top, or of stopping the continuous supply of gas to the boilers and hot-blast stoves, and at his own furnaces he had not had any explosion of gas for many years; but with a plenum of pressure he thought there must always be a difficulty in getting the air to enter freely at the places where it had to be burnt. This was the reason why gas might very frequently be observed burning at the chimney tops of stoves and boilers, where the blast furnaces were close-topped. In the open-topped plan, while one furnace was standing for casting, there was still an ample supply of gas from the others for all the heating purposes required; and at his own works a considerably larger quantity of gas might have been obtained from the furnaces, if sufficient requirements had existed for its employment when taken off.

The Chairman moved a vote of thanks to Mr. Cochrane for his paper, which was passed.

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The Meeting then terminated; and in the evening a number of the members dined together in celebration of the Twenty-second Anniversary of the Institution.

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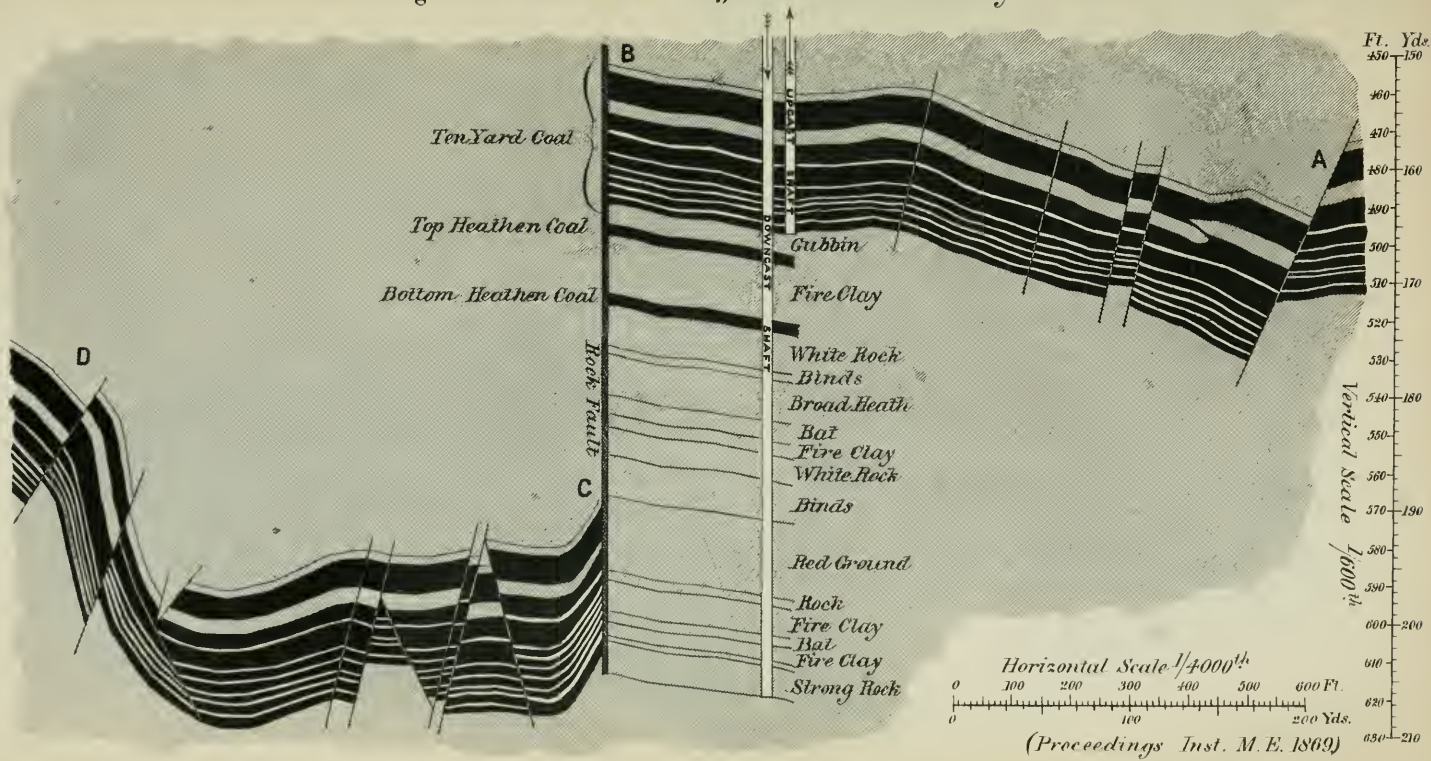
# VENTILATING FAN.

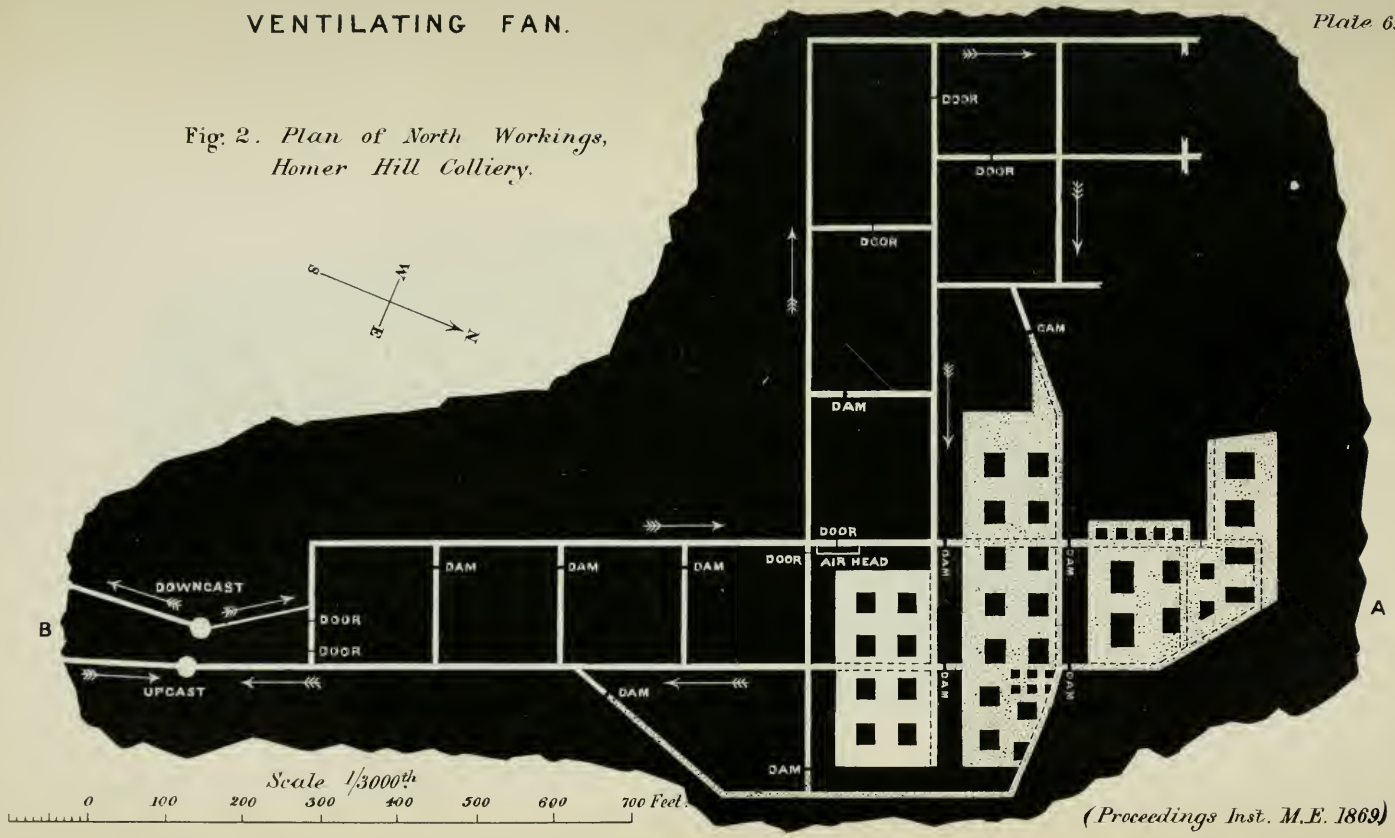
Plate 5.

Fig. 1. *Section of Workings, Homer Hill Colliery.*



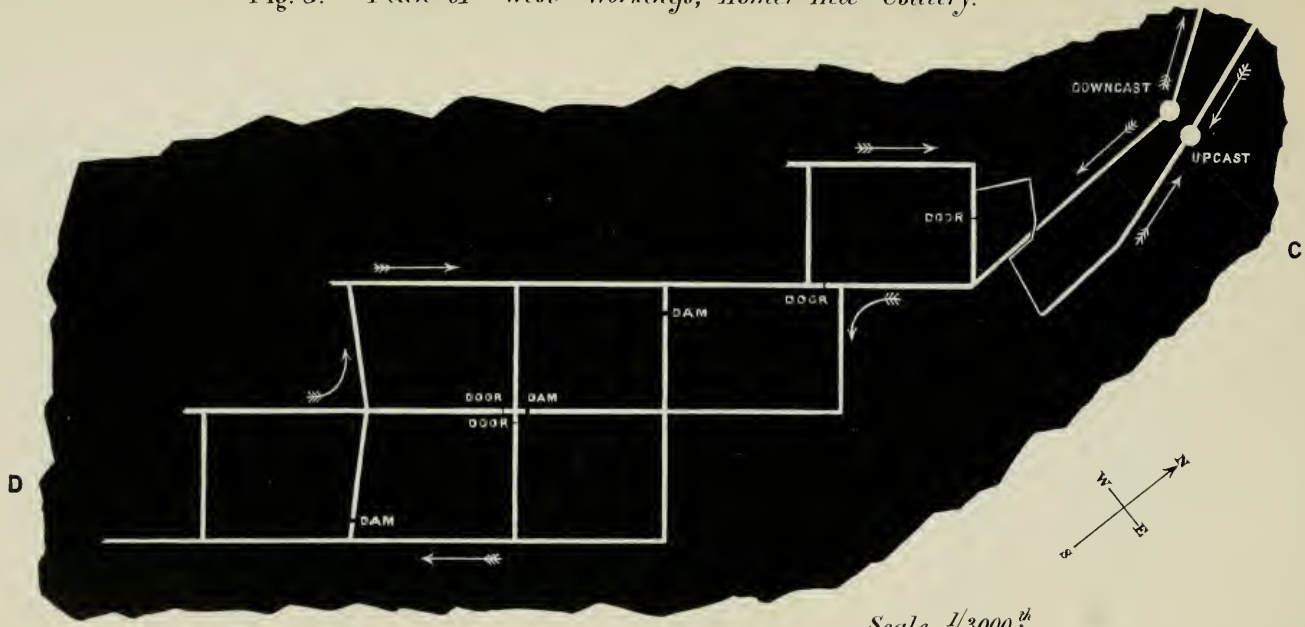

(Proceedings Inst. M. E. 1869)

Fig. 2. *Plan of North Workings, Homer Hill Colliery.*




*(Proceedings Inst. M.E. 1869)*

Fig. 3. *Plan of West Workings, Homer Hill Colliery.*




Scale 1/3000th

0 100 200 300 400 500 600 700 800 Feet.

*(Proceedings Inst. M.E. 1869.)*

# VENTILATING FAN.



Fig. 4. *Struvé's Ventilator.*

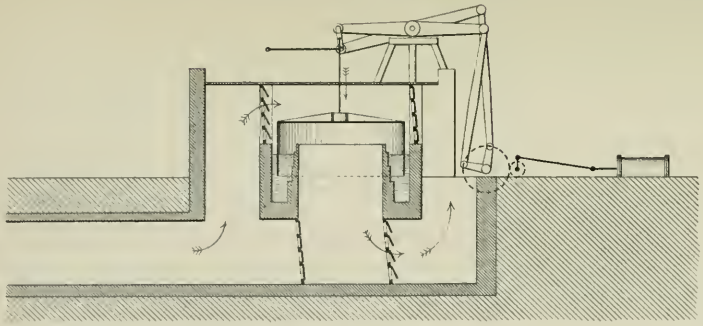
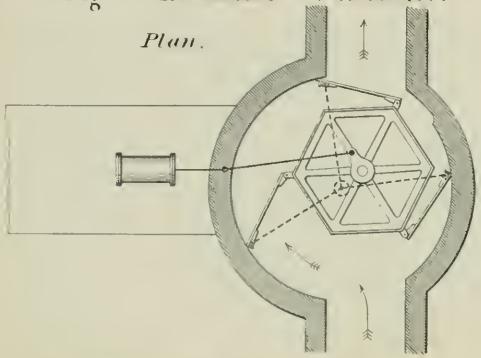


Fig. 5. *Lemielle's Ventilator.*

*Plan.*



*(Proceedings Inst. M.E. 1869.)*

*Nasmyth's Ventilator.*

Fig. 6.

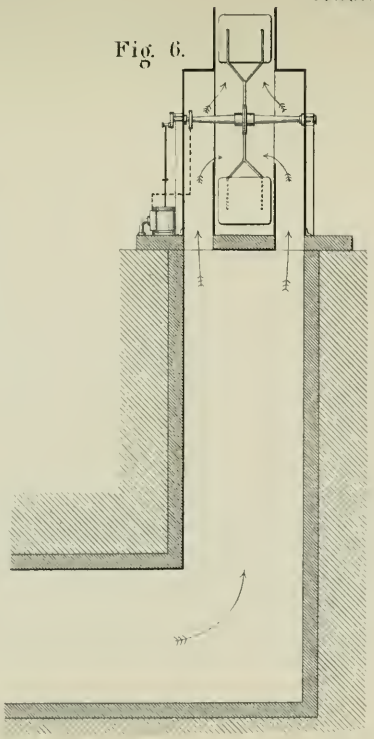
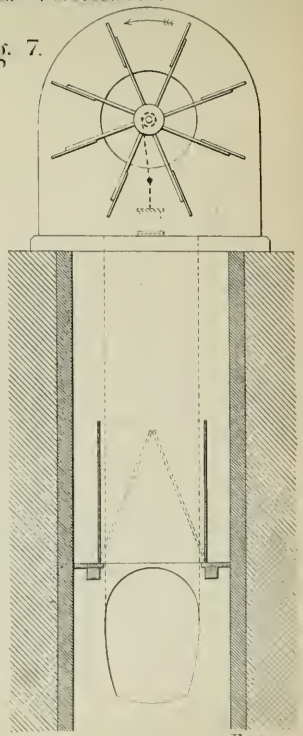


Fig. 7.



*Scale* 1/150

0 5 10 15 20 25 30 Feet.

# VENTILATING FAN.

*Guibal's Ventilator.*

*Plate 9.*

Fig. 8.

*Section of Shaft and Ventilator.*

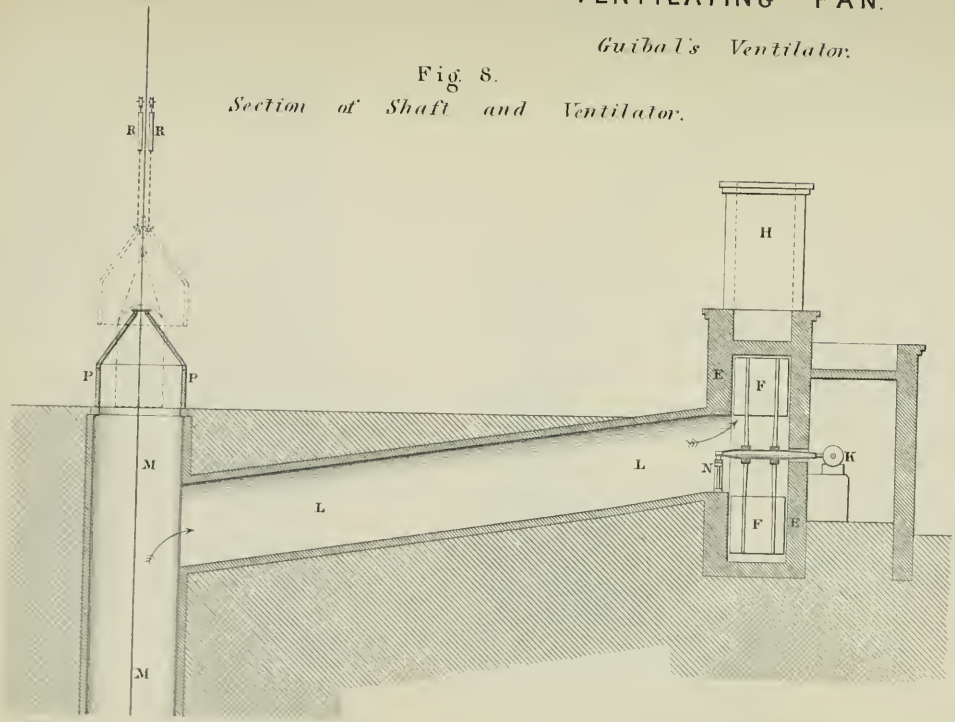
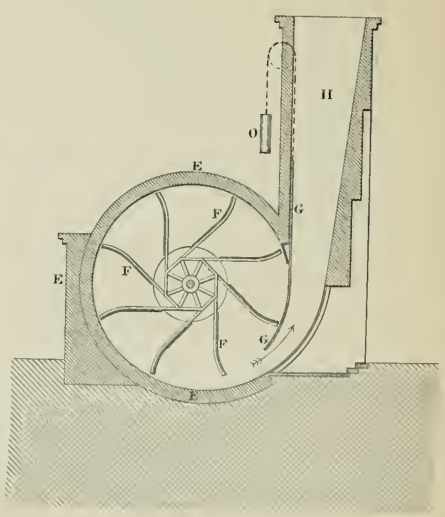



Fig. 9.

*Transverse Section.*




*(Proceedings Inst. M. E. 1869.)*

*Scale* $\frac{1}{200}$ *th*

# VENTILATING FAN.

*Plate 10.*

Fig. 10. *Longitudinal Section.*

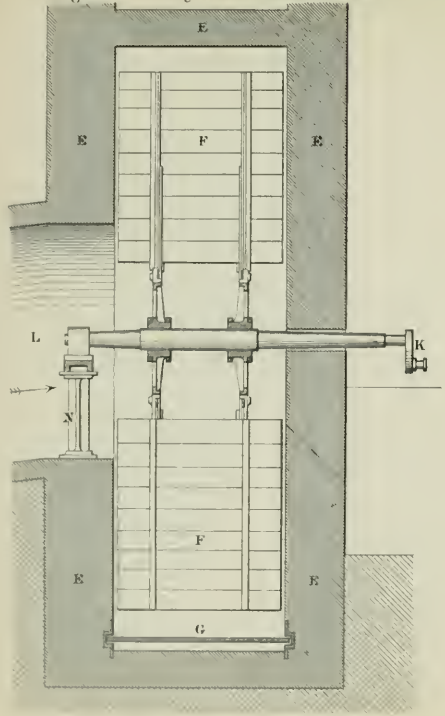
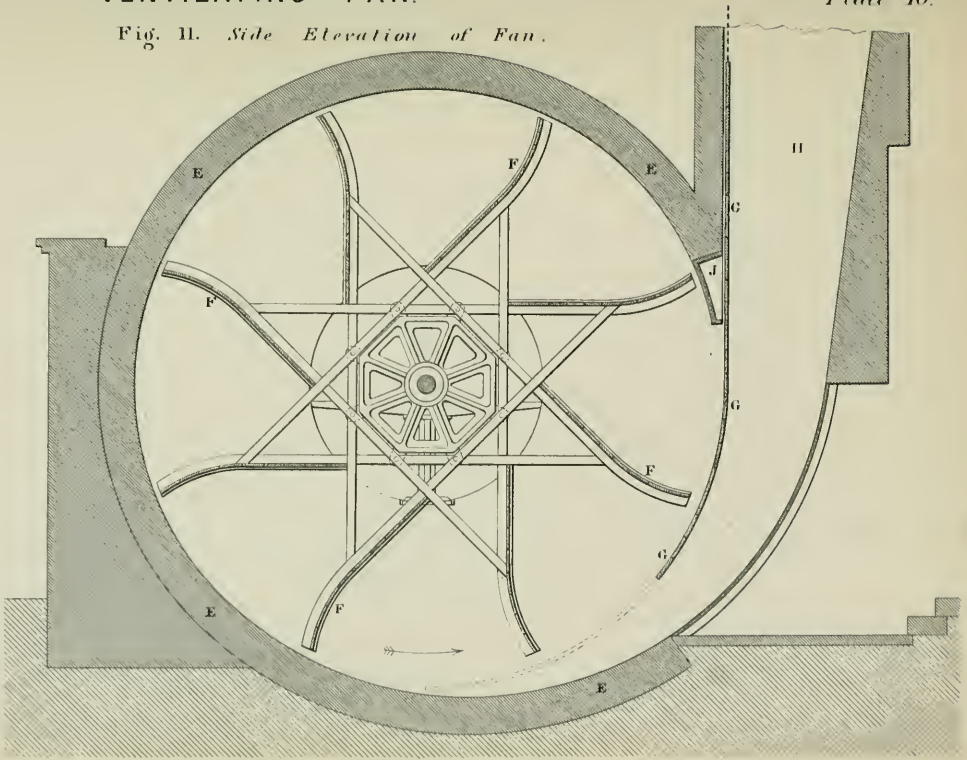



Fig. 11. *Side Elevation of Fan.*




*(Proceedings Inst. M.E. 1869.)*

*Scale* $\frac{1}{60}$*th*

0 5 10 15 20 *Feet.*

Fig. 12. *Elevation of Engine.*

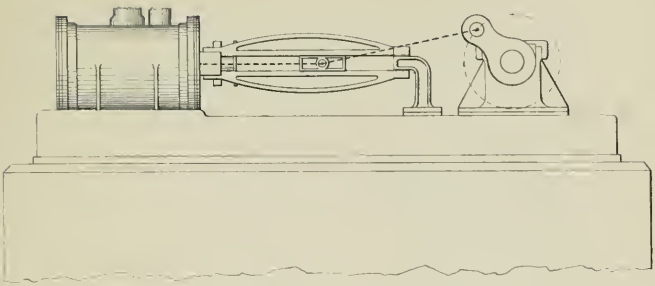


Fig. 13. *Plan of Engine.*

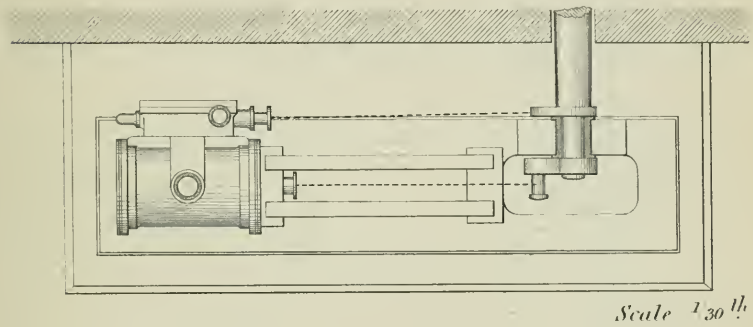
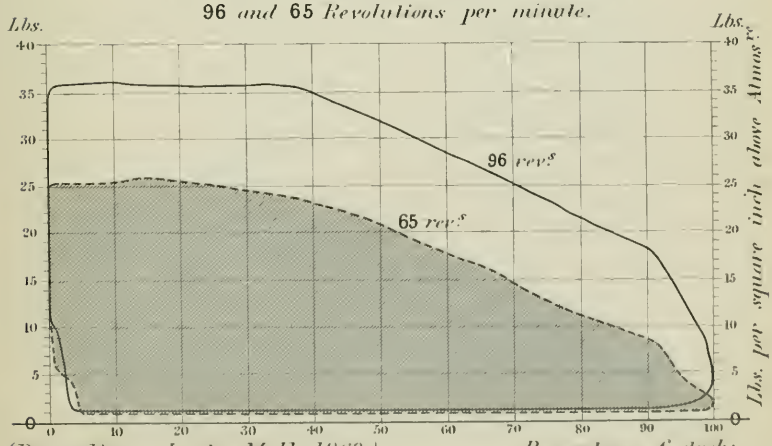



Fig. 14. *Indicator Diagrams from Engine* 96 *and* 65 *Revolutions per minute.*

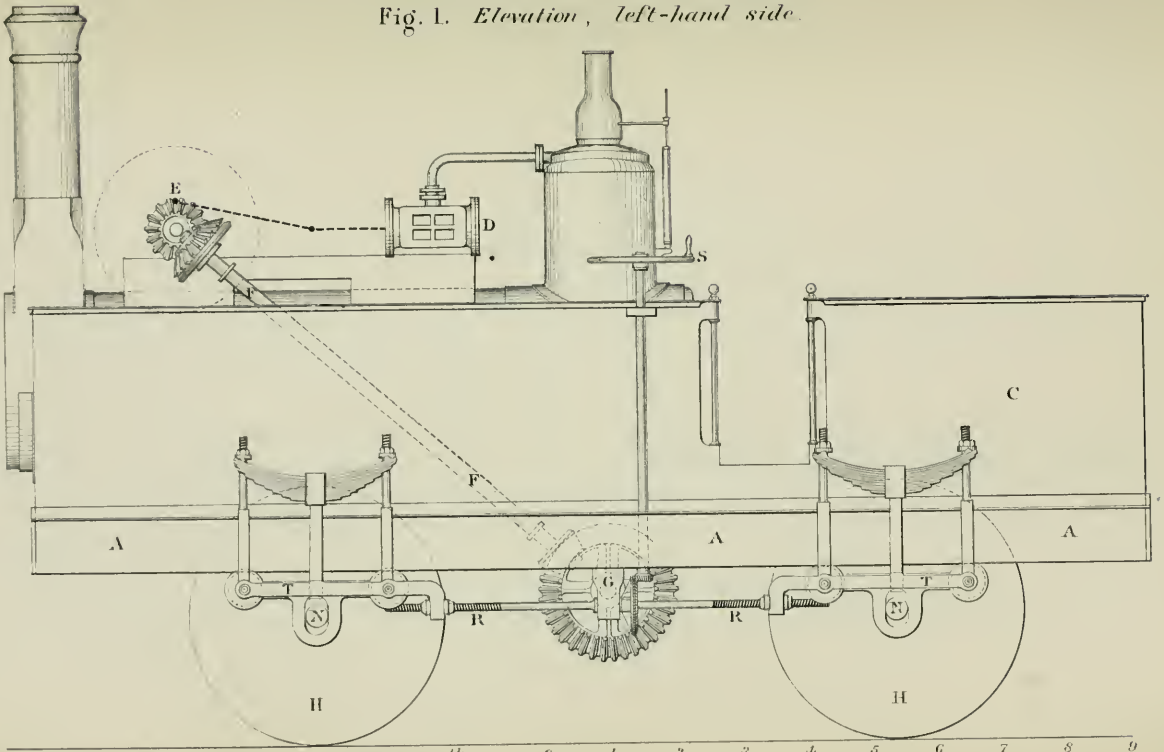



*(Proceedings Inst. M. E. 1869.)*

# STEAM ROAD ROLLER.



Fig. 1. *Elevation, left-hand side.*

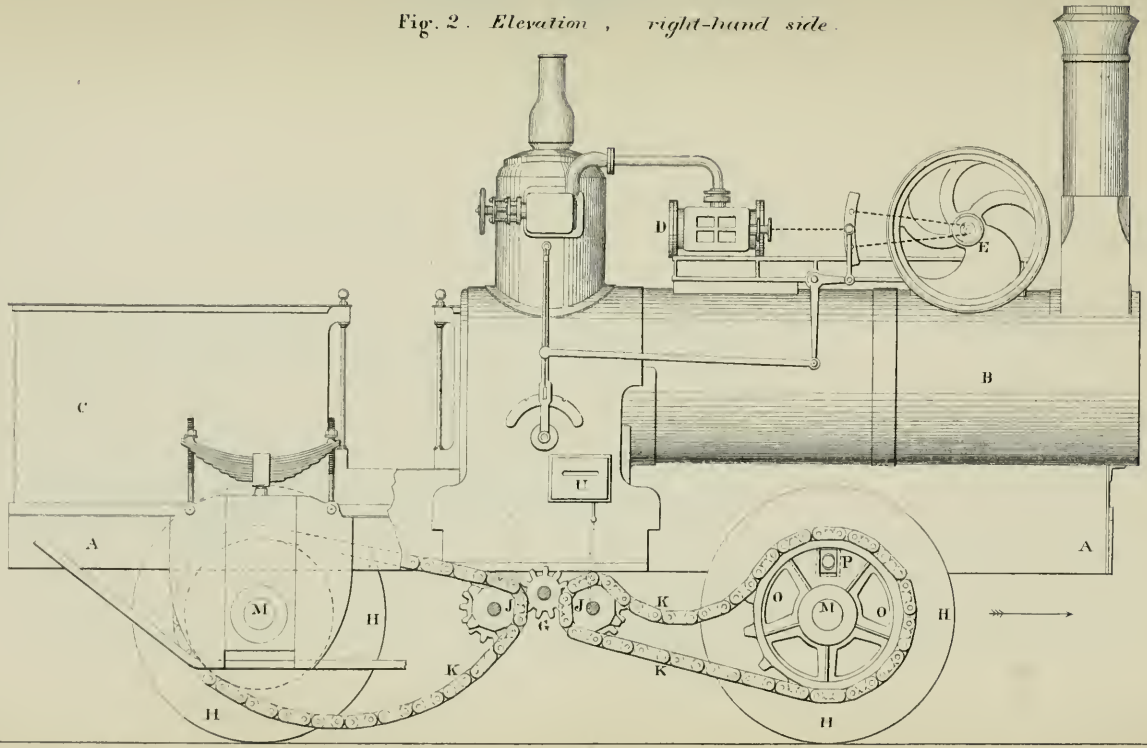



*(Proceedings Inst. M. E. 1869.)* *Scale 1/35th*

# STEAM ROAD ROLLER.

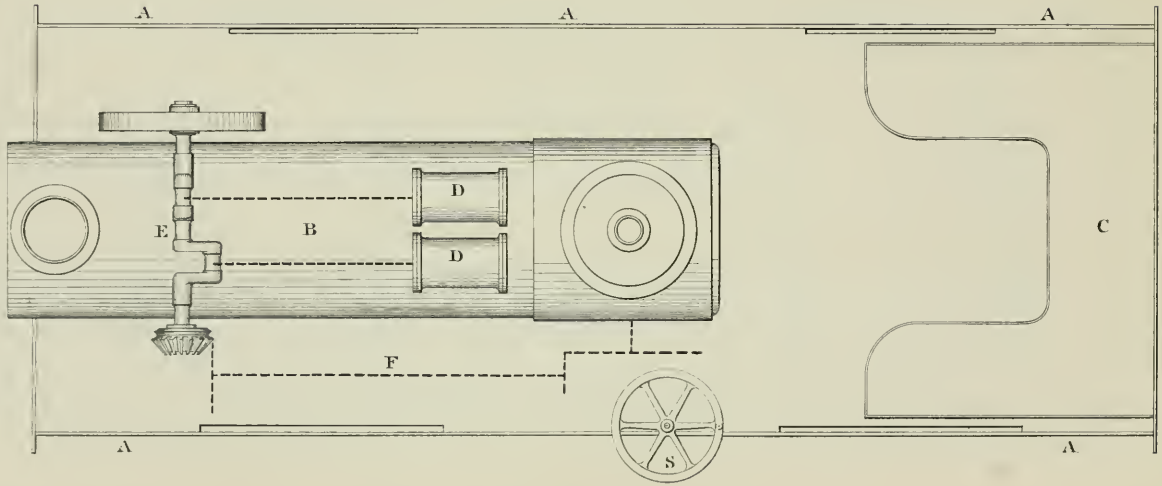


*Fig. 2. Elevation, right-hand side.*



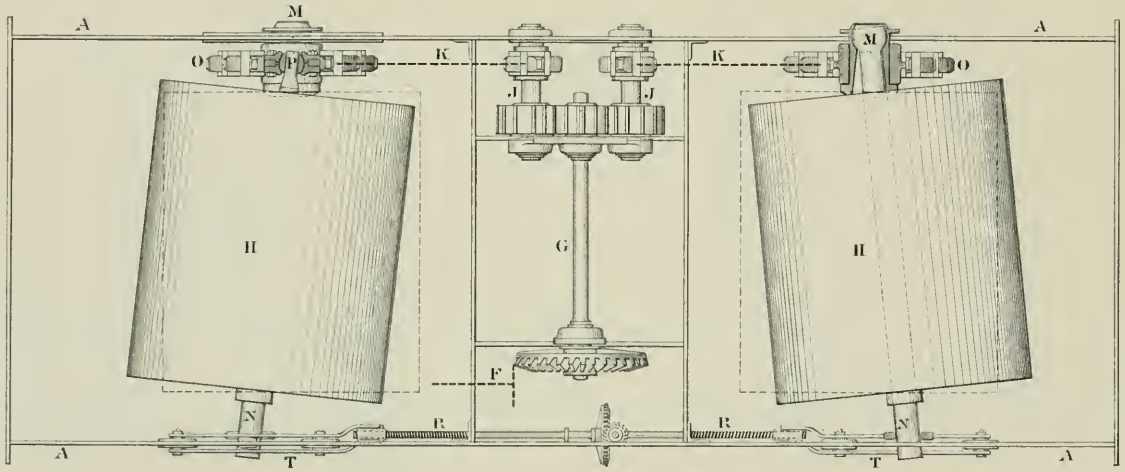

*(Proceedings Inst. M. E. 1869.)* *Scale 1/35th* 0 1 2 3 4 5 6 7 8 9 10 Feet.

Fig. 3. *Plan.*




*(Proceedings Inst. M.E. 1869)* *Scale 1/35th* 0 1 2 3 4 5 6 7 8 9 10 Feet.

Fig. 4. *Plan below Boiler.*




*(Proceedings Inst. M. E. 1869)* *Scale 1/25 th* 0 1 2 3 4 5 6 7 8 9 10 *Feet.*

Fig. 5. *Transverse Section in middle.*

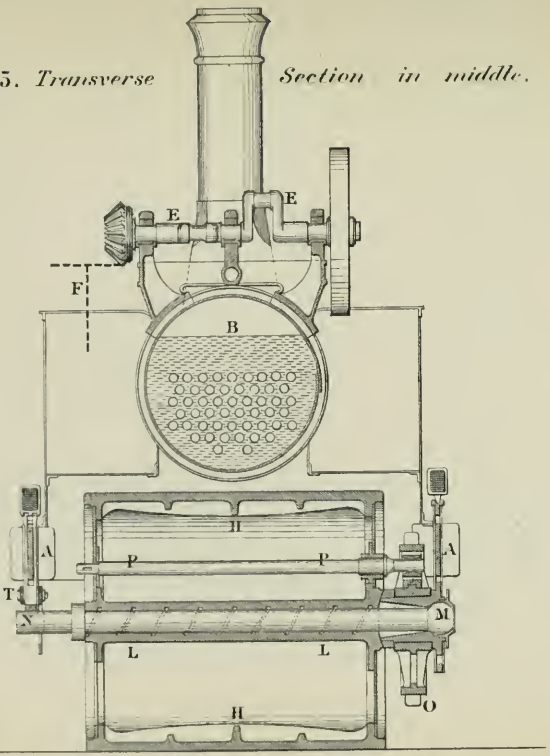
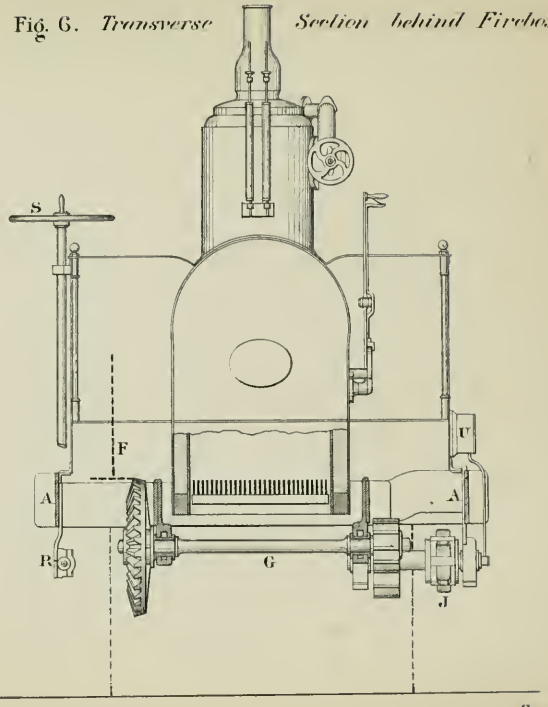
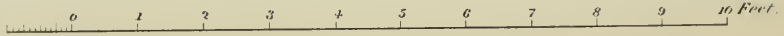



Fig. 6. *Transverse Section behind Firebox.*




*(Proceedings Inst. M. E. 1869.)* *Scale 1/35th*



# PROCEEDINGS.

29 April, 1869.

The General Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 29th April, 1869; Sampson Lloyd, Esq., Vice-President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman announced that the Ballot Lists had been duly opened, and the following New Members were found to be elected:—

MEMBERS.

| | |
|---|---|
| William George Beattie, | London. |
| William Boyd, | Newcastle-on-Tyne. |
| Frederick Carpmael, | London. |
| William Clark, | Alfreton. |
| William Clarke, | Gateshead. |
| Joseph Bramah Cochrane, | Dudley. |
| Henry Worton Elliott, | Birmingham. |
| Thomas Crump Hambling, | London. |
| Arthur Keen, | Birmingham. |
| Alfred Keep, | Birmingham. |
| Humphrey Campbell Lockhart, | Birmingham. |
| Thomas Mabbutt, | Birmingham. |
| James Nelson, | Sunderland. |
| John Player, Jun., | Swansea. |
| John Purves, | Liverpool. |
| Alexandre Schanschieff, | Newport, Mon. |
| Samuel Sharrock, | Liverpool. |

ASSOCIATE.

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| John Varley, | Sheffield. |

The following paper was then read:—

# DESCRIPTION OF GUIBAL'S VENTILATING FAN EMPLOYED AT THE HOMER HILL COLLIERY, CRADLEY.

By Mr. JAMES S. E. SWINDELL, of Kingswinford.

The Homer Hill Colliery, at which this Ventilating Fan is employed for the entire ventilation of the workings, is situated at Cradley near Stourbridge, at the south west of the South Staffordshire coalfield, and consists of about 90 acres of the Thick or Ten Yard coal. The colliery has been in operation between three and four years, and the plant and machinery are capable of raising 600 tons of coal per day.

The coal seam in that locality is very much cut up by numerous faults, as shown by the section of this colliery in Fig. 1, Plate 5, which is taken along the line A B C D upon the plans, Figs. 2 and 3, Plates 6 and 7. In the section, Fig. 1, there first occurs, beginning at the right-hand side, a piece of coal extending 200 yards distance; then a down-throw at A, bringing the top coal to face the bottom coal; then a length of 380 yards from A to B, followed by another down-throw of 31 yards from B to C; then a length of 300 yards, and an up-throw of 15 yards at D; and still further to the west two or three smaller faults. These faults together with numerous fissures or "black things" cause the ventilation of this colliery to require more than ordinary care; and it is from one of these last-named fissures that the gas which caused an unfortunate explosion in this colliery about a year ago is supposed to have issued, having been brought down by the falling roof or "shut." Two shafts have been sunk, as shown in the section, Fig. 1, each 7 ft. 6 ins. diameter. The downcast shaft is carried to a depth of 202 yards for getting the lower portions of coal lying between the two largest faults; and the upcast shaft is sunk to a depth of only 165 yards to the upper portion of the coal. A "jackey" pit 19 yards deep and an inclined road connect the lower and upper portions of the seam, and by means

of this pit and road the air of the ventilation current returns from the lower workings to the upcast shaft.

Coals are being raised at both shafts in cages having a sectional area in plan of 20 square feet, thus leaving for the passage of the air in the shafts by the side of the cages an area of about 24 square feet, the total sectional area of each shaft being 44 square feet. Previous to the application of the present mechanical ventilation, when the extent of the workings was small and only natural ventilation from the heat of the workings was used without the aid of a furnace, it was found that the cages acting as moving pistons in the shafts reversed the current of air every time they ascended or descended; and the consequence was that, if during the time the colliery was standing, say from Saturday till Monday in any week, a quantity of gas had accumulated at the working faces, this had to be driven backwards and forwards and in fact churned up with the air, until sufficiently diluted to allow of men entering the workings. This state of circumstances, especially with rapidly extending workings, could not be allowed to go on; and it was consequently suggested by the writer that a mechanical ventilator should be adopted. As however a mechanical ventilator had never been used previously for the Thick coal workings, it had to be considered whether a ventilating furnace would not be better for the purpose; but after the question had been thoroughly gone into, it was decided to adopt mechanical ventilation, and the plan of ventilator to be employed had then to be determined upon.

Amongst the earlier plans for the mechanical ventilation of mines, Struvé's Ventilator, described at a former meeting of this Institution (see Proceedings Inst. M. E. 1859 page 32), was introduced in South Wales twenty years ago. It is shown in Fig. 4, Plate 8, and is a gigantic pump, consisting of a pair of inverted cylindrical vessels like gasholders, each 16 feet diameter, which are worked up and down alternately with a 6 foot stroke in annular tanks of water contained within closed chambers. They thus produce the effect of double-acting pumps, drawing in the air from the pit at the top and bottom of each vessel alternately through large inlet flap-valves,

and discharging it at the next stroke through corresponding outlet flap-valves. The vessels are worked up and down by a pair of beams driven by a steam engine with gearing. This ventilator working at five double strokes or 60 feet per minute delivered 13,000 cubic feet of air per minute.

Lemielle's Ventilator, which was also described at a former meeting (see Proceedings Inst. M. E. 1858 page 63), was used extensively at that time in the collieries of France and Belgium. It is shown in plan in Fig. 5, Plate 8, and consists of a horizontal hexagonal drum revolving eccentrically within a cylindrical casing, 14 feet diameter and 7 feet deep, and carrying three vanes, which are made to open and close during each revolution by eccentric arms, like a feathering paddle-wheel; the drum works close against one side of the casing, giving a passage for the air on the opposite side only. By the rotation of the drum therefore the air is drawn in at one side of the casing and discharged at the other side, in a manner similar to the passage of the steam in some forms of rotary engines. This ventilator working at 21 revolutions per minute delivered 16,000 cubic feet of air per minute with a vacuum of 0·8 inch water gauge, the velocity of the tips of the vanes being 900 feet per minute.

The simplest form of mechanical ventilator was Nasmyth's Ventilating Fan, which was described at a meeting of this Institution in 1856 by Mr. Ebenezer Rogers, as then used by him for the ventilation of a fiery pit at Abercarn in South Wales, where it proved very efficient and safe in action (see Proceedings Inst. M. E. 1856 page 251). This ventilator, shown in Figs. 6 and 7, Plate 8, consists of a simple fan with eight radial vanes, $13\frac{1}{2}$ feet diameter and $3\frac{1}{2}$ feet width, driven direct by a small vertical steam engine coupled to a crank on the end of the fan shaft. The fan works within a casing enclosed only at the two sides and entirely open round the circumference; and it draws the air in at the centre on each side. It ran at a speed of 60 revolutions per minute or 2500 feet per minute velocity of the circumference, and delivered 45,000 cubic feet of air per minute; the lineal velocity of the air current in the upcast shaft was 800 feet per minute, with a vacuum of 0·5 inch water gauge.

The two mechanical ventilators first referred to involve a complication of construction and a consequent risk of accidental derangement and stoppage, which form a serious objection to the introduction of mechanical ventilation in the place of furnace ventilation; but the fan ventilator is so simple, compact, and substantial in its construction, as to be free from this objection. The Guibal Ventilating Fan having been seen by the writer at work in the North of England, where it had been selected for use by several mining engineers after careful comparison with other plans of mechanical ventilation, he became satisfied from the results of examination that it was the best fan hitherto tried for the ventilation of collieries; and it was consequently adopted for the Homer Hill Colliery, where it has now been running about nine months, doing excellent work, without a single stoppage for repairs of any description.

This ventilating fan, which is the invention of M. Guibal of Belgium, is shown in Figs. 10 and 11, Plate 10, Fig. 10 being a longitudinal section, and Fig. 11 a side elevation; and the general arrangement of the ventilator at the colliery is shown in Figs. 8 and 9, Plate 9.

The ventilating fan F is 16 ft. 6 ins. diameter and 4 ft. 9 ins. wide, and is driven by a horizontal steam engine K, Fig. 8, coupled direct to a crank on the shaft of the fan. The engine is shown in Figs. 12 and 13, Plate 11; it has a 10 inch cylinder with 16 inch stroke, and is made of simple construction, very strong and durable. The steam for working the engine is supplied from the winding engine boilers at 50 yards distance, by a 3 inch pipe laid in sand underground, the pressure of steam being 40 lbs. per square inch. Indicator diagrams are shown in Fig. 14, taken from the engine with the fan running at the speeds of 65 and 96 revolutions per minute, and these show the horse power to be $7\frac{1}{4}$ and $17\frac{1}{2}$ respectively in those cases.

The ventilator consists of an outer casing of brickwork E, Figs. 10 and 11, the rotating fan F, an adjustable shutter G at the discharge orifice, and an outlet chimney H. The casing E is a ring

of brickwork 14 inches thick, about two thirds of the circumference being a circle concentric with the fan, and the remaining portion eccentric and with a larger radius, so as to enlarge the casing gradually towards the point of discharge. The upper portion of the arch springs from a cast-iron girder J, Fig. 11, which extends across the opening into the chimney, and is formed of a wedge-shaped section to connect the two lines of brickwork. The side of the chimney, which forms the continuation of the bottom of the casing, is carried up inclining outwards, thus gradually increasing the sectional area of passage up to the top: the other three sides of the chimney being vertical, Figs. 8 and 9. The sides of the fan casing E are closed by vertical walls of brickwork 20 inches thick, Fig. 10; and a circular opening 6 ft. 7 ins. diameter is made in the centre of one side for admitting the air from the mine to the fan. This opening is connected by a drift L with the upcast shaft M, as shown in Fig. 8; the drift is $35\frac{1}{2}$ square feet in sectional area and 43 feet long.

The centre framing of the fan consists of two cast-iron octagonal centres 4 ft. 7 ins. diameter, Figs. 10 and 11, which are keyed upon the main shaft made of wrought iron 7 inches diameter; and on each of the eight sides of these castings is bolted a wrought-iron arm made of a flat bar $3\frac{1}{2}$ inches by $\frac{3}{4}$ inch; these arms are bolted together where they cross one another, so as to form a strong and light frame. The eight vanes of the fan are made of $1\frac{1}{4}$ inch deal, bolted to angle-irons that are rivetted upon the wrought-iron arms; the vanes are each 4 ft. 9 ins. wide and 5 ft. 7 ins. long, giving an area of 26 square feet, and they work with 1 inch clearance at each edge from the side walls and 2 inches clearance from the circumference. Each vane is inclined backwards through the inner half of its length at an angle of 45° from the radial direction; and the outer half is curved forwards to the extent of 10 inches at the end. The inner ends of the vanes extend to 3 ft. 2 ins. distance from the centre, the clear space in the centre being about 3-8ths of the diameter of the fan. The outer end of the fan shaft works in a carriage fixed upon a cast-iron girder N, Figs. 8 and 10, which extends across the inlet opening in the side wall of the fan casing E; and the inner end of the shaft is carried upon the engine bed, Figs. 12 and 13. When the fan is running at

its usual working speed of 26 revolutions per minute, the outer ends of the vanes move at the speed of 1350 feet per minute, but the speed of the engine piston at the same time is only 70 feet per minute.

The adjustable sliding shutter G, Fig. 11, at the outlet side of the fan casing, is made of $1\frac{1}{4}$ inch deal boards similar to those of the vanes of the fan, sliding in cast-iron grooves that are built into the side walls ; these grooves are made to the same circle as the upper part of the fan casing, with the same clearance from the tips of the vanes. The boards forming the sliding shutter are bolted to flexible strips of hoop iron, so as to allow of their freely following the curved groove ; and the shutter can be raised or lowered as desired by means of a chain passing over a pulley near the top of the outlet chimney, with a balance weight O, Fig. 9, the upper end of the shutter sliding up within the chimney. This adjustable shutter is used in the varying conditions of the underground workings, for securing the most effective results from the fan by adjusting from time to time the area of discharge opening in accordance with the quantity of air to be discharged at any time. The opening of the outlet chimney is 3 ft. 3 ins. by 4 ft. 11 ins. at the bottom, and increases to 6 ft. by 4 ft. 11 ins. at the top, giving an area of discharge of 29·4 square feet. The total height of the chimney is 32 feet from the bottom of the fan.

In applying the ventilating fan at the colliery, an arrangement had to be made for covering the top of the upcast shaft, in order to prevent the air from being drawn in by the ventilator at the top of the shaft instead of from the workings below. There were two ways of doing this: either to enclose and cover a sufficient extent of ground round the shaft for allowing the tubs to be changed within closed doors; or to have a moveable cover over the shaft, to be raised like the ordinary fence at the mouth of the shaft every time the cage ascended. The latter method was adopted as the simplest and most convenient, and it has been found to answer every purpose. The moveable cover of the shaft, as shown in Fig. 8, consists of a rectangular wood box P, about 6 feet square and 3 ft. 6 ins. high, upon which is a pointed roof with a hole 8 inches square at the top for the winding rope to work through; and this hole is covered with

a loose sliding piece of wood, through which the rope works in a close fitting hole, so that every time the rope oscillates laterally this sliding piece moves freely with it in any direction, without uncovering the larger hole. The moveable cover is connected to two balance weights R by chains passing over pulleys fixed at the top of the conductors; and the cage every time it reaches the top of the shaft raises the cover, as shown by the dotted lines in Fig. 8, the strain being relieved from the winding rope by the balance weights, so that the cover as now balanced is not so heavy on the rope as the ordinary fence at the other shaft.

The course of the current of air in the workings of the colliery is shown by the arrows on the plans, Figs. 2 and 3, Plates 6 and 7. The current passes from the downcast shaft to the first split at a depth of 165 yards, where the greater portion passes along the gate roads for a distance of 810 yards in the upper workings, returning by the gate roads and air head for 500 yards distance to the upcast shaft. The remaining portion of the in-going air descends to the second split at a depth of 202 yards, and passes along the gate roads 530 yards to the lower workings, returning by the gate roads and jackey pit and air head, 710 yards distance to the upcast shaft. Here it joins the return air from the first split; and the whole quantity of air passes into the ventilating fan through the inclined drift L, Fig. 8, of 43 feet length, which goes off from the upcast shaft at 6 feet depth below the surface.

The fan is kept running in ordinary working at about 26 revolutions per minute, at which speed 13,600 cubic feet of air per minute pass into the ventilator with a vacuum of 0·15 inch water gauge. This supply of air is found to keep the workings well ventilated, their average temperature being only 54°, and only 60° in the hottest portion of the workings even when the temperature was 75° at the top of the downcast shaft on the hottest day observed. The fan can be got up to full speed from standing in only about one minute's time. At the speed of 65 revolutions per minute, 37,500 cubic feet of air per minute pass into the ventilator, with a vacuum of 1·02 inch water gauge;

and at the extreme speed of 96 revolutions per minute, 51,700 cubic feet per minute pass into the ventilator, with a vacuum of 1·75 inch water gauge.

When the ventilator is standing still with the adjusting shutter wide open, about 9,130 cubic feet of air per minute pass through it from the natural current of ventilation due to the heat of the workings. When the ventilator is stopped after running at 26 revolutions per minute and delivering 13,600 cubic feet of air per minute, the quantity of air passing through it in the sixth minute after stopping is 4,260 cubic feet, and in the sixteenth minute 4,080 cubic feet, the adjusting shutter in this case being only half open. When it is stopped after running at 65 revolutions per minute and delivering 37,500 cubic feet per minute, the air passing through it in the sixth minute afterwards is 4,790 cubic feet, and in the sixteenth minute 4,400 cubic feet, the shutter being half open.

The lifting of the cover at the top of the upcast shaft and the passage of the cages in the two shafts affect the vacuum in the fan drift in the following manner, as shown by the water gauge placed about midway in the drift, when the fan is running at about 65 revolutions per minute :—

| | Water Gauge. |
|---|---|
| Cover open and cage empty | 0·95 inch. |
| Cover closed and cage standing still | 1·10 „ |
| Cover closed and cage beginning to descend in upcast shaft | 1·25 „ |
| Both cages half way in the two shafts | 1·45 „ |
| Cage reaches bottom of upcast shaft | 1·15 „ |
| Cage ascending in upcast shaft | 1·05 „ |
| Both cages half way | 1·00 „ |
| Cage at top of upcast shaft and empty, and cover open as at first | 0·95 „ |

Whilst the cover is open at the top of the upcast shaft during the changing of the tubs, 7-16ths of the total quantity of air passing into the ventilator is drawn in direct from the surface through the open top of the shaft, occasioning a momentary loss of that amount in the ventilation of the workings. This occurs about once every minute when the pit is in full work, and the cover remains open for about six seconds each time, or one tenth of the whole time of working.

The total loss of air from the uncovering of the pit top amounts consequently to less than 1-20th of the whole work of the ventilating fan.

One object in the design of the Guibal ventilating fan is to discharge the air into the atmosphere with as low a final velocity as possible; because whatever excess of velocity there is in the discharged air beyond the velocity of the ascending current in the shaft is an absolute waste of power. The ascent of air in the shaft at the Homer Hill Colliery being 13,600 cubic feet per minute with the ventilator running at 26 revolutions per minute, and the sectional area of the shaft being 44·2 square feet, the velocity of the current of air in the shaft is about 300 lineal feet per minute. The velocity of the air in rotation at the circumference of the fan at the above speed of 26 revolutions per minute is 1350 feet per minute or $4\frac{1}{2}$ times the velocity of the ascending current in the shaft; but the area of the orifice of the outlet chimney being 29·5 square feet, the air cannot have a greater velocity at its exit, if it fills the outlet chimney, than 460 feet per minute, or only $1\frac{1}{2}$ times the velocity of the current in the shaft. The surplus moving power in the quicker moving air at the extremities of the fan arms is therefore restored by the retarding of the current at the outlet, instead of being lost as would have been the case if the fan had discharged direct into the air round its whole circumference.

Another object in this ventilator is to obtain the maximum useful effect of the fan under each of the varying circumstances under which it has to work in order to meet the requirements of the mine ventilation: because the fan can only work to the best advantage with the exact area of discharge opening that is suited to the quantity of air to be discharged in each case, and the resisting pressure at that particular time. If the discharge opening is too large, a back current into the fan from the upper part of the discharge opening is produced, causing a waste of power by putting useless air into motion: and if on the other hand the discharge opening is too small, an unnecessary resistance to the discharge of the air is produced, with a consequent waste of power.

The following case that occurred at the Homer Hill Colliery will illustrate the facility with which the ventilator can be immediately adapted to any alteration in the requirements of the ventilation. A length of about 70 yards of gate road having been cut off from the course of ventilation, it soon became filled with gas; and in order to remove the accumulation of gas and allow the men to enter this portion of the workings, a dam sheet was put across the in-going airway, just beyond the entrance to the gate road that had to be cleared of gas, thereby partially stopping the passage of the air current; and an air pipe was carried from the entrance of the gate road through a fixed dam into the return air passage. The ventilator was then set running at double speed, about 60 revolutions per minute, thus maintaining the ordinary ventilation of the pit by drawing the same quantity of air past the sides and bottom of the dam sheet as had previously with the ordinary speed of 26 revolutions per minute been passing through the unobstructed airway before the dam sheet was put up. The remaining portion of the air being forced into the gate road that was charged with gas, began immediately to drive the gas forward through the air pipe, and the gas was cleared from the gate road as fast as the air pipe could be extended along it from the entrance by laying down additional lengths of pipe; the whole of the accumulation of gas was thus cleared out in the course of a few minutes throughout the entire distance, without interfering with the regular ventilation of the pit.

In the use of the ventilating fan, as the ventilation of the pit is dependent upon the continuous working of a piece of machinery, it has been contemplated to provide by the erection of a duplicate engine and fan against any accident happening to the machinery; but the construction of the engine and fan is so simple and durable, and the wear and tear so slight in consequence of the very moderate speed of working, that no such provision of duplicates has yet been made in any instance; and in the writer's opinion it is only in the case of a fiery mine that any such provision will really be required. The liability of the ventilator to get out of order is exceedingly small; and no accidents of any consequence to the maintenance of the ventilation have yet occurred with any of the fourteen ventilators

now at work at different mines, some of which are as large as 30 feet diameter and 10 feet width, and capable of delivering 100,000 cubic feet of air per minute with a vacuum of 3 inches column of water.

The cost of working the ventilator for 24 hours at a speed of 65 revolutions per minute is as follows :—

| | *s.* | *d.* |
|---|---|---|
| 3¾ tons of Slack, at 2*s.* 9*d.* per ton . . . . | 10 | 3 |
| Oil and grease . . . . . | 0 | 3 |
| Total . . | 10 | 6 |

This amount has been obtained from an actual trial of 24 hours, when the winding engine was not at work, and the boiler was supplying steam only to the ventilator engine. In ordinary work however at the lower speed of 26 revolutions per minute, the actual steam used by the ventilator engine amounts to little more than the surplus steam that unavoidably occurs with the irregular working of the winding engine, which would otherwise be wasted. No expense is incurred for attendance, as the stoker of the winding engine is sufficient for looking after the ventilator engine.

The total cost of the ventilating fan, engine, and connections, has been about £500. The cost of an ordinary ventilating furnace to give the same quantity of air as is now obtained from the ventilating fan —with the cost of the dumb drift across the measures that would be required for delivering the heated air into the upcast shaft at a sufficient height from the bottom to be safe from fire—and with the extra cost of replacing the wooden conductors by iron ones for the cage working in the shaft, on account of having to use the upcast shaft as a working shaft—would amount to a total of about £1500, as compared with £500 the total cost of the mechanical ventilator.

The cost of working such a furnace may be inferred from the following examples. At a colliery in the South Yorkshire district, having the upcast shaft about 80 yards deep with an average temperature of 240° for obtaining a supply of 50,000 cubic feet of air per minute, the cost of working the ventilating furnace is about £1500 per annum. The shaft in this instance is cased with cast-iron tubbing for 50 yards of its length, and the effect of the heat is found

to be most injurious; the cast-iron tubbing is obliged to be wedged up once a month at great expense, and on each of these occasions the proper ventilation is interfered with in consequence of the temperature of the shaft having to be lowered whilst the men are at work in it.

At Pelton Colliery in Durham, where one of the Guibal ventilators has replaced a ventilating furnace, the following is the comparison of the two modes of ventilation. The depth is 180 yards, and with the furnace the average temperature was 235° in the upcast shaft, the quantity of air circulated 48,000 cubic feet per minute, and the vacuum 0·9 inch water gauge; and the consumption of coals was 90 tons per fortnight. With the fan the consumption was 60 tons per fortnight, with nearly double the quantity of air supplied, or 82,370 cubic feet per minute, and a vacuum more than double, or 2·15 inches water gauge. In order to obtain such an increased volume of air with the furnace ventilation, so high a temperature would have been required in the upcast shaft as probably to be impracticable; and the consumption of coals would have been increased to about 290 tons per fortnight, instead of the 60 tons consumed by the fan for the same work.

Thus where the fan has replaced the furnace, it has been proved by actual comparison that the economy of coal resulting from the change is very great. If indeed fuel were the only consideration, there would no doubt be a certain depth of shaft, combined with other conditions, at which a given quantity of coal could be burnt in a furnace so as to produce a current of ventilation equal to that produced by the consumption of the same quantity of coal in raising steam for working a ventilating fan. Such a depth however could not be less than 400 yards, and would involve an extraordinary high temperature in the upcast shaft with the furnace ventilation. The presence of cast-iron tubbing in the upcast shaft, even though protected with firebrick, and also of pump or steam pipes, is a very serious objection to the adoption of a furnace; and when the upcast shaft is a working shaft, the wear and tear becomes enormous, and the heat and smoke from the furnace render the shaft almost useless for men to work in it. In the case of the Homer Hill Colliery it is estimated that to produce a current of 45,000 cubic feet per minute,

with a vacuum of 1 inch water gauge, an average temperature of about 150° would be required in the upcast shaft if a furnace were employed.

The result of the above comparison of actual working at the Pelton Colliery between the furnace and the fan is that, with a consumption of only two thirds the quantity of coals, the fan ventilation supplies nearly double the amount of air as compared with the furnace.

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The CHAIRMAN remarked that, considering the enormous loss of life annually occurring in the working of the coal mines in this country from defective ventilation, a more interesting and important subject could scarcely be brought before the Institution than that of the paper just read, which described the introduction into the South Staffordshire district of a more perfect system of ventilation than had hitherto been adopted. The use of a fan for the purpose of ventilating a mine was not indeed new, and two previous papers on ventilating fans had been read at former meetings of the Institution, but those plans had not come into general use; the Guibal fan however now described was so remarkably simple and so efficient that it might be expected to supersede completely the ordinary system of furnace ventilation hitherto prevalent in this country. Having witnessed the working of the fan at the Homer Hill Colliery he had been greatly pleased with its performance, and the whole structure of the machine as well as of the colliery plant generally presented a marked contrast to the rough class of machinery and the rude modes of working which prevailed at the collieries in that district; it was indeed equal to the best of the machinery that he had seen in any other parts of England or in other countries. The ventilation produced by the fan appeared to be practically as good as could possibly be desired; for standing in the drift leading from the upcast shaft to the fan, he had found that, when the fan was working at only about 26 revolutions per minute,

the air coming from the mine was very little inferior for breathing to the open atmosphere.

Mr. T. Evans, Government Inspector of Mines for the Midland Counties, said he had seen almost all the fans and mechanical ventilators now used at the coal mines in England; and he was very much pleased to find they were now being introduced into South Staffordshire, believing as he did that for shallow mines mechanical ventilation was the only known means of producing a sufficient current of air for safe working. In deep shafts, furnace ventilation would do as well as mechanical; but in fiery mines, whether shallow or deep, it was most objectionable to have a fire down in the pit. With regard to Struvé's ventilator, the one referred to in the paper had been constructed many years ago; those more recently erected at Risca, Lletty Shenkin, and other collieries were giving good results. He considered them excellent machines for ventilating mines, the only objection to them being their liability to derangement consequent on the great number of flap valves necessarily used. The Guibal fan was now being employed extensively in the North of England, the Midland Counties, and South Wales, and he believed gave great satisfaction. At the Staveley Colliery in North Derbyshire one of these fans had now been in constant work about $2\frac{1}{2}$ years, and had not cost anything for repairs; in that case two engines were fixed on the same bedplate for driving it, so that in the event of any accident happening to one of them while at work, it could be disconnected and the other engine coupled to the fan without loss of time. The great feature in the Guibal fan was the slow velocity at which it delivered the air, so that there was but little power lost in the discharged air; whereas in the Nasmyth fan used at Abercarn the air was delivered at a high velocity; and instead of supplying itself entirely from the mine, the fan drew in much of the air direct from the surrounding atmosphere, and consequently the ventilation in the mine was low in proportion to the power of the fan. Two other descriptions of fans were now in course of erection for colliery ventilation, and he thought they would be attended with success. One was the fan of Mr. Waddle of Llanelly, which was a closed fan, with solid sides

attached to the vanes, and open only at the circumference, revolving on a horizontal shaft in the open air without requiring any external casing, the air from the mine being drawn in through a central circular aperture at one side, and discharged all round the circumference direct into the atmosphere; the width between the two sides of the fan was diminished gradually towards the circumference, and the vanes were straight and were inclined backwards from the radial direction. One of these fans of about 30 feet diameter was now being put up by Messrs. Barber and Walker at the High Park Colliery near Nottingham, which was expected to produce a ventilation of 120,000 cubic feet of air per minute and a vacuum of 2 inches water gauge; the fan was intended to supersede the ventilating furnace hitherto used at that colliery, as the furnace was not giving a sufficient quantity of air, and the action of the fire on the cast-iron tubbing was doing considerable damage. The air from the top of the upcast shaft was conveyed through a large culvert to the central aperture in the side of the fan, and discharged at the circumference; the fan was made of thin iron plates rivetted together. The other new fan now being introduced for colliery purposes was that of Mr. Rammell, which was a closed fan, taking in the air at both sides and discharging it through a contracted opening at the circumference direct into the atmosphere; the original fan was used for exhausting the Pneumatic Despatch tube at Euston Square, and one was now being erected at the Shipley Colliery near Derby, which was to be about 30 feet diameter, and to make about 150 revolutions per minute, supplying 120,000 cubic feet of air per minute with $2\frac{3}{4}$ inches water gauge vacuum. He had no doubt this would prove an efficient machine, but its relative value as compared with the Guibal fan remained yet to be ascertained by the results of working. A fan very similar to these two new ones that he had referred to had been erected at the Cwmsaebran Colliery by the late Mr. Brunton, and had worked there for many years.

Mr. J. S. E. Swindell said the particulars had been received from Staveley of the Guibal fan employed there, which had been set to work in the autumn of 1866, and had been working ever since

without intermission, and had never caused the least trouble. The fan was 30 feet diameter and 10 feet wide, and was driven at about 60 revolutions per minute during the day and 50 at night; and the quantity of air delivered by it at different speeds and the percentage of power utilised had been found to be as follows, taking the percentage upon the total power in the steam supplied to the engine:—

| Revolutions per minute. | Water Gauge. Inches. | Cubic Feet of Air per minute. | Percentage of Power utilised. |
|---|---|---|---|
| 32 | 0·70 | 43,852 | 40·38 |
| 51 | 1·70 | 86,283 | 43·09 |
| 64 | 2·77 | 101,773 | 53·27 |
| 68 | 3·10 | 110,005 | 53·85 |

So satisfactory had the results of this fan been, that a second fan was now being erected at the Staveley Collieries; and another had been made for the Alfreton Colliery, which had already been working for some time, and had also given great satisfaction. With regard to the Waddle fan which had been referred to, he had made enquiries about it before erecting the fan at the Homer Hill Colliery, but from the information that he had obtained it appeared that on trial it was found to be considerably inferior to the Guibal fan in the useful effect produced by the power expended.

Mr. J. P. Baker, Government Inspector of Mines for South Staffordshire and East Worcestershire, said he had seen the working of the fan at the Homer Hill Colliery, and was very glad the important step had at length been taken of introducing mechanical ventilation into that district, in order to supersede the present dangerous practice of ventilating by a fire at the bottom of the pit. No matter how well the ventilating furnace might be constructed, it was well known that there was always danger of the fire igniting the coal, and this danger was especially great in the Thick Coal pits of the South Staffordshire district, on account of the unusual thickness of coal through which the furnace drift had to be carried to the upcast shaft. By the adoption of the fan however all this danger was entirely got rid of; and considering the simplicity of its construction and the small cost of working, in addition to the safety attending its use, he hoped the fan would be extensively employed in the

South Staffordshire collieries, and that naked fires in the pit shafts and seams of coal would be for ever done away with. It might not be necessary to adopt mechanical ventilation for very small collieries where only a few men were employed; but in such a pit as the Homer Hill Colliery there could be no question as to its advantage. For a colliery of that size the cost of £1500 for a ventilating furnace, as named in the paper, including the expense of making the inclined drift through the strata from the furnace to the upcast shaft, appeared to him rather excessive. With the fan the ventilation now obtained was three times as much as was ordinarily required for the colliery: for on some occasions when he had been in that mine 7,000 cubic feet of air per minute had been sufficient to keep it clear of gas; and it appeared from the paper that the ordinary ventilation with the fan running at the usual speed of 26 revolutions per minute was 13,000 cubic feet per minute, while at the higher speed of 65 revolutions 37,000 cubic feet of air per minute were passed through the mine. One drawback that struck him in the fan arrangements was the loss of power by drawing in air direct from the mouth of the upcast shaft during the times that the cover at the top of the shaft was lifted by the cage; and the loss then occurring of 7-16ths of the ventilating power was a large deduction from the efficiency of the fan, and might be found a serious drawback in case the mine ever became fiery, although under ordinary circumstances it was seen that the surplus ventilating power of the fan was amply sufficient to compensate for such a loss. The fan at the Homer Hill Colliery was the first and at present the only one in the South Staffordshire district, but he trusted it would lead the way to a more general adoption of mechanical ventilation.

Mr. J. S..E. Swindell remarked that the loss of effect by drawing in air at the top of the upcast shaft when the cover was raised was 7-16ths of the ventilating power during the time only that the cover was raised, which amounted to only about 1-10th of the whole time of working; so that the total loss was only 7-16ths of 1-10th, or less than 1-20th of the whole quantity of air drawn through the fan.

Mr. F. J. Bramwell observed that in the case of the ventilating fan at the Abercarn Colliery, to which reference had been made in

the paper, there was an arrangement provided for doubly closing the top of the upcast shaft and preventing air from being drawn in there, by placing a pair of folding doors a little distance down in the shaft, just above the air drift leading off to the fan; these doors were intended to be closed, after the cage had passed through them in ascending, before it lifted the moveable cover at the top of the shaft, so that in that plan there would be no time at which the air could be drawn in direct at the mouth of the upcast shaft by the fan.

Mr. E. A. Cowper considered the necessity for closing the top of the upcast shaft was the only objection attending the adoption of mechanical ventilation. With a ventilating furnace at the bottom of the pit the column of air in the upcast shaft was maintained always lighter than that in the downcast shaft, so that the current of ventilation would always follow the same course in the two shafts, without the necessity for closing the top of either; but as soon as mechanical means were employed to draw the air up the upcast shaft, it became necessary to close the top of that shaft, so as to ensure the air entering the mine by the downcast shaft. The simplest plan for closing the shaft to which the fan was connected, when used for winding, was he thought the one referred to in the paper, namely by roofing over the top of the shaft with a sort of house or room at the surface of the ground, completely closed all round, and with double doors on the opposite sides for running the skips in and out. The men engaged in loading and unloading the cage would thus be working in fact in the upcast shaft itself, or rather in a chamber at the top of it; and there would not be the trouble of lifting a cover at the top of the shaft or opening doors in the shaft, both of which arrangements he thought were attended with some danger, because although the weight of the cover was balanced the ascending skip must give it a blow to put it and the balance weight suddenly in motion, and this involved a risk of accident.

With regard to the construction of the fan and casing, he thought the form adopted was decidedly not the one suited for obtaining the most advantageous results from the power expended, and that the casing should be in the form of a spiral. In an extensive series of experiments that he had formerly made on blowing fans, for the

purpose of ascertaining the best proportions, a result was ultimately obtained of as much as 75 per cent. effective power out of the total power expended in driving the fan; and in that instance the casing of the fan was made in the form of an arithmetical spiral, according to the plan originated by Ericson. The annular space beyond the tips of the vanes increased uniformly round the circumference of the fan till it attained the full size of the discharge orifice; so that at one quarter of a revolution the area of passage in the fan case beyond the tips of the vanes was one quarter of the area of the discharge outlet, and half way round the circle it was half the outlet area, and three quarters round it was three quarters of the outlet area; and the side of the delivery passage leading from the fan case was made to be a tangent to the circle described by the tips of the vanes. There were four straight radial vanes, each of which was able, in consequence of the spiral form of the casing, to do its full share of work in discharging the air into the casing throughout the entire revolution; because the discharge of the air from the vanes in any part of their revolution was not impeded by the area of passage between the tips of the vanes and the casing being too small in proportion to the quantity of air that had to pass at that part of the circle. The blowing fan being 5 feet diameter, the proportions found to give the best results were 16 inches width and 11 inches length for the vanes; and the spiral casing was 7 ft. 4 ins. diameter increasing to 7 ft. 11 ins., and 20 inches wide inside. The fan was run at a speed of $712\frac{1}{2}$ revolutions per minute or 11,192 feet per minute velocity of the circumference, at which speed a pressure of 5·62 inches of water was maintained with an outlet opening of 2·46 square feet area. The theoretical velocity of discharge due to that pressure being 9173 feet per minute gave an effective power in the discharged air of 19·9 horse power, whilst the indicated horse power of the engine was 26·4 horse power, exclusive of the friction of the engine, giving a result of 75·3 per cent. effective power. From these results he had calculated that for the purpose of colliery ventilation a fan of similar construction, 8 ft. 3 ins. diameter and 2 ft. 9 ins. wide, with vanes 2 ft. 6 ins. wide and 1 ft. 7 ins. long, running at 310 revolutions per minute, and requiring about 11 horse power to drive it at that speed, would

discharge 45,000 cubic feet of air per minute, with a vacuum of 4 inches water gauge, which he believed was the vacuum required in large collieries. It seemed to him therefore an unnecessary expense to employ a large fan for ventilating a colliery, when the same extent of ventilation could be obtained at less cost with a small fan running at a high speed; and he considered the small fan would be equally applicable and equally economical in working.

Mr. J. S. E. Swindell feared that a small fan running at a high speed would get out of order before it had been working very long, and he had understood that small fans had been tried for colliery ventilation, and that large fans had subsequently been put up instead of them. He had therefore considered it better to go to the expense of a large fan in the first instance. With regard to the mode of closing the top of the upcast shaft, the plan of housing it over in the manner that had been mentioned had been considered, but the moveable cover described in the paper had been adopted instead, as a simpler and less expensive arrangement. There was an objection he thought to the other plan that had been referred to of putting double doors in the shaft, because the men employed at the pit mouth were not always so careful as would be necessary, and if the opening of the doors should happen not to be attended to when the cage was descending, an accident would be occasioned. The proper way no doubt would be to have two separate shafts, instead of making the present upcast shaft serve the double purpose of a winding as well as a ventilating shaft; the separate ventilating shaft could then be permanently covered over at the top, and there would then be always a downcast current in the other large open shaft used for winding with two cages, and an upcast current in the closed shaft, undisturbed by drawing in any air at the top of the shaft.

Mr. E. A. Cowper said the blowing fan which he had described had been running constantly for nine years at the speed of about 700 revolutions per minute without ever getting out of order; and the speed would be only 310 revolutions per minute in the small fan which he had calculated for supplying a ventilation equal to 45,000 cubic feet per minute with a vacuum of 4 inches of water; but with less vacuum a lower speed would be sufficient.

Mr. T. Evans thought it questionable whether a small quick-running fan would last as long as one of the large fans going at a slow speed, and also whether it would do the work of ventilation with equal certainty and at the same cost as the large fan.

Mr. F. J. Bramwell observed that it was very satisfactory to hear from thoroughly practical men such strong expressions of confidence in the efficiency of mechanical ventilation for collieries. It had always seemed to himself a most irrational procedure to burn a large quantity of coals at the bottom of the upcast shaft, with the object of establishing by their combustion what might be called a mere chimney draught, when it was known that a far better effect might be obtained from the same amount of fuel by applying it to drive a ventilating fan; and although the application of mechanical ventilation to collieries had long been objected to on account of the danger which might arise should that ventilation fail, yet at the same time the use of a large fire was advocated, in close proximity to an atmosphere liable at any time to be explosive. With respect to the particular fan described in the paper, it appeared to him to be at variance with the results that had been established in the long experience with blowing fans, which must he considered apply also to ventilating fans. The spiral form for the casing was not only correct in theory, but it had been conclusively established by practice as the proper form; but the casing now shown partook of the spiral form through only one third of the circumference of the fan; the position and shape of the vanes also differed from what he believed had been found the most advantageous, particularly in the vanes being here curved forwards at their outer extremity; and these differences could not fail to have an important effect in diminishing the results obtained from the power expended in driving the fan, and he was satisfied the effective power realised must be low in amount with such a construction. A properly proportioned and well balanced fan he had no doubt would run at a considerable velocity with as much safety and as little stoppage for repairs as at a low velocity; but if an objection were felt to adopting a high speed with the correspondingly small size of fan for colliery ventilation, and

the larger fan running at a slow speed were preferred, still the construction and proportions and the form of the casing that had been proved to be most advantageous in the small fan should be adhered to in the larger fan.

Mr. J. S. E. Swindell said he had not had an opportunity himself of making experiments upon the effect of variations in the form of the Guibal fan, but from a number of experiments made at the time of its introduction in the North of England he understood that the form of blades and shape of casing shown in the drawings had been found to give the best results, and he had accordingly adopted that construction for the fan at the Homer Hill Colliery, which had been made by Messrs. Black and Hawthorn of Gateshead. With the fan running at 65 revolutions per minute the indicator diagram showed that the power expended in driving it was $7\frac{1}{4}$ horse power, and at 96 revolutions per minute the horse power was $17\frac{1}{2}$; but at those speeds the ventilation obtained was far beyond the requirements of the mine.

Mr. T. Evans mentioned that in the experiments which he had made with the Guibal fan at Staveley, which was similar in construction to that now described, he had found the utilised power amounted to about 50 per cent. of the power expended in driving the fan.

Mr. J. E. Swindell said that as the proprietor of the Homer Hill Colliery he was very glad to have taken the first step in introducing an improved mode of ventilation in the South Staffordshire district, fully concurring as he did in the remarks that had been made as to the imperfect manner in which mining operations had been carried on in that district. Without entering into the question of the best construction of fan, he could speak of very important practical advantages which he had experienced from the use of the fan, in the fact that on several occasions when most of the pits in the district had been kept standing, from their ventilation being interrupted by the influence of unfavourable atmospheric conditions, the whole of the three miles length of gate roads in the Homer Hill Colliery had been completely cleared and ventilated in 20 minutes, enabling the men to go to work as usual. In the case of ironworks

where the mills and forges were dependent upon a regular supply of coal from the pits in connection with them, this was a matter of considerable importance, the ironworks being in such cases kept idle when the pits were standing; and this inconvenience and loss he had himself experienced at his own works previous to the adoption of the ventilating fan. During the whole period however that the fan had now been in operation, the men had never yet had to play a single day at his works in consequence of the want of proper ventilation in the mine, although his forges and mills were supplied from this colliery. He hoped the proprietors of all large collieries would adopt mechanical ventilation, not merely on account of the great advantages which they would themselves derive from it, but also for the sake of the comfort and safety which it ensured to the men.

The CHAIRMAN remarked that in witnessing the working of the fan at the Homer Hill Colliery he had not looked into the question whether its construction was perfectly in accordance with the most approved mechanical principles, but he had certainly never seen a fan working more easily or more steadily, or more efficiently performing the work of ventilation for which it was designed; and the main consideration he thought was to get the ventilation of a colliery successfully performed by mechanical means in place of the ordinary ventilating furnace.

He proposed a vote of thanks to Mr. Swindell for his paper, which was passed.

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The following paper, communicated through Mr. Heaton of Birmingham, was then read:—

# DESCRIPTION OF THE STEAM ROAD ROLLER USED IN PARIS.

By M. GELLERAT, of Paris.

This Steam Road Roller consists of a locomotive engine carried entirely upon two large cast-iron rollers of equal size, which extend the whole width of the machine and are both driven by the engine. The entire weight of the machine is thereby rendered available both for rolling the road and for propelling the machine, which is thus able to start readily in either direction without any slipping. It is the only construction of road roller in which none of the weight is dragged, but the whole is made available for adhesion in driving; and this is considered by the writer to be essential for rendering a road roller really complete, as machines having only one driving axle are liable to slip at starting, thereby wasting power and causing damage to the road surface that is being rolled. The weight of the machine is equally divided upon the two rollers, and the adhesion for driving is so great that these machines have worked up hills with a gradient of 1 in $12\frac{1}{2}$. Whether the direction of motion is forwards or backwards is entirely indifferent, which is an important advantage in a machine for rolling roads. The machine is guided by inclining the roller axles out of parallel to each other, making them converge to the centre of the circle that is being traversed; by this means it is guided with facility and certainty along difficult and winding roads, and can travel readily round very sharp curves. The communication of the driving power is maintained direct to both the rollers, however much they may be inclined to each other when running round a curve.

These road rollers have now been in regular use in Paris for four years, and the results of their working have so thoroughly established them as an important source of economy and durability in the repair

of the roads, that they are used for the whole of the roads in Paris and the suburbs, eight of the machines being now employed there. They are the invention of M. Ballaison, and have been worked out and matured by the writer's firm, by whom those now working in Paris have been made.

The roller is shown in Figs. 1 to 6, Plates 12 to 16. Figs. 1 and 2 are elevations on the left and right sides; Fig. 3 is a plan at the top, and Fig. 4 a plan of the rollers and gearing below the boiler; and Figs. 5 and 6 are transverse sections in the middle of the machine and behind the firebox.

The machine has a longitudinal wrought-iron frame A A, Figs. 1 to 3, like a locomotive engine, with cross bearers to carry the boiler B, and a water tank C at the back of the foot-plate. The boiler is tubular, with a copper firebox and brass tubes, Figs. 5 and 6, like a locomotive; it is 2 ft. 8 ins. diameter and $6\frac{1}{2}$ feet long, and contains 51 tubes of 2 inches diameter, giving 260 square feet of heating surface; the firebox has 25 square feet of heating surface. The boiler is proved up to 130 lbs. per inch, and is worked at a pressure of 80 to 90 lbs. per inch.

The engine has a pair of horizontal cylinders D D, Fig. 3, 7 inches diameter and 11 inches stroke, fixed on the top of the boiler, and working a transverse crank-axle E, which drives by bevil gear an inclined shaft F that is carried down at the left side of the boiler, Fig. 1, and is geared at the bottom to a transverse horizontal shaft G extending across the middle of the machine underneath the firebox. The opposite end of this horizontal shaft G carries a spur pinion, which drives two similar pinions J J, one in front and the other behind, Figs. 2 and 4; and on the axle of each of these is a chain-pinion for driving the two large carrying rollers H H by the chains K.

The rollers H are each 3 ft. 11 ins. diameter and 4 ft. 7 ins. long. They are cast-iron cylinders of $1\frac{1}{2}$ inch thickness with intermediate strengthening ribs and internal flanges at the ends, to which wrought-iron plate covers are fixed, closing the two ends of the rollers, as shown in Fig. 5. The axles are stationary and the rollers run loose

upon them, the bearing of each roller consisting simply of a cast-iron cylinder L extending the whole length of the roller with a continuous bearing on the axle, and furnished with a spiral groove for lubrication; this bearing L is carried in the centres of the plate covers closing the ends of the roller.

The rollers are arranged so as to allow of being inclined out of parallel with each other for guiding the machine, by making the axles converge to the centre of the circle to be traversed, either to the right hand or to the left. For this purpose one end of each axle is stationary and is made spherical, as shown at M in Figs. 4 and 5; and the axlebox is opened out conically on the inner face, to allow of an oblique position of the axle horizontally, and also of any vertical displacement from the play of the bearing springs on uneven ground. The spherical axle end has a feather projecting below to keep it from revolving, although it is free to move obliquely. The inner face of the axlebox, where the end of the roller bears against it, is also made with a spherical surface having the same centre of curvature as the spherical end of the axle, so as to follow all the movements of the roller and keep always in steady contact with it. The other end of each axle is plain, and is carried in a forked bearing N, Figs. 1 and 4, which is cut away on each side sufficiently to allow for the oblique positions of the axle.

The axlebox at the spherical end M of each axle is made cylindrical on the exterior, and this exterior portion forms the centre upon which revolves the large chain-wheel O, driven by the endless chain K from the chain-pinion J in the middle of the machine, Figs. 2 and 4. The chain-wheel O runs loose upon the cylindrical exterior of the axlebox, and is coupled to the carrying roller H by a projecting pin P fixed in the roller, Fig. 5; the vibration that occurs during each revolution when the roller is oblique is allowed for by the end of the pin having a parallel journal without collars, free to slide lengthways in its bearing, and the bearing itself slides radially with parallel cylindrical sides between two spokes of the chain-wheel O, and is also slightly coned out on both faces in the radial direction, as shown in Figs. 2 and 5. By this arrangement, whilst the two rollers are perfectly free to shift

horizontally with their axles converging or diverging to a considerable extent, the chain-wheels O O retain their position, and are driven direct by the engine, without interference from the change in position of the rollers.

The inclination of the roller axles to each other is effected by means of the right-and-left-handed screw R, Figs. 1 and 4, worked from the foot-plate of the engine by the hand-wheel S, which serves as the steering wheel for the machine. The screw R causes the plain ends of the roller axles to approach or recede from each other; and these ends do not work in axleboxes, but each end is simply guided horizontally by a moveable axleguard T, which carries the brass step for the axle bearing and is capable of sliding along the engine frame A to a certain extent on either side of its central position. The top of the axleguard T is made in the form of a long sliding frame, which embraces the engine frame A, bearing against it by two small rollers underneath, and carrying the bearing spring above.

The driving chains K, Fig. 2, are made of single and double links alternately, engaging on the teeth of the chain-wheels O, the links and pins being made of steel. After a certain amount of work the chains get lengthened by the pin holes wearing oval; the slack of the chain is then taken up by shifting the axleguards at that end of the rollers a little further apart, for which a provision is made in their fixing. The chains can then be worked for a further time, after which the pin holes of the chains are rebored and larger pins put in, the axleguards being then brought back to their original position. This reboring of the holes is carried out twice, thus giving a long period of work to the chains before they have to be renewed. The whole of this driving gear is made very strong and durable, and it has been found completely successful in work.

The rollers in the first of these machines were made with separate wrought-iron wheel centres, upon which was bolted a cylinder of boiler-plate; but this make was abandoned in consequence of the frequent failure of the bolts, which were sheared off by the stretching of the cylindrical plate from rolling

out. The present cast-iron rollers, heavier than the original wrought-iron ones but less expensive in make, have proved very satisfactory; they have done a large amount of work without any expense for repairs, some of them having run as much as 3,000 miles without any sign of cracking or splitting. The first cast-iron rollers were made quite cylindrical; but as it was found that the surface became worn down more at the end next the chain-wheel than at the other end, the rollers have since been cast slightly conical, with the larger end next the chain-wheel, so that when half worn down they may be truly parallel. One end cover of each roller has a manhole in it, to allow of access to the interior for oiling the bearing.

Two sizes of the machine are used in Paris, one weighing 15 tons and the other 30 tons in average working order. The smaller one, which is the machine that has been described and shown in the drawings, has rollers 3 ft. 11 ins. diameter and 4 ft. 7 ins. long; and in the larger one the rollers are 4 ft. 9 ins. diameter and 6 feet long. A third intermediate size of 22 tons weight is also used, but this is somewhat different in construction from the one now described.

These road rollers were adopted for rolling the roads of Paris, in consequence of the satisfactory results of a series of experiments that were made with them under the direction of M. Michal, Director of the municipal service, by M. Homberg, Engineer-in-Chief of the public roads of Paris. The rollers are hired at a fixed charge for rolling, according to the weight of the machine and the distance run in work, the rate being 7*d.* by day and 8*d.* by night per ton per mile of the machine. This includes all expenses of wages, coals, and materials for working and repairs: excepting the supply of water, which is furnished by the municipal authorities. The contract is for seven machines for a period of six years, to be employed wherever required by the authorities within the line of the fortifications of Paris or in the Bois de Boulogne or Vincennes. All the seven machines have to be maintained constantly in working order, except that each is allowed to be stopped for repairs for three consecutive days in each month, but there are never to be more than three of

the machines off work for repairs at the same time. Any delay in the work, unless from admitted unavoidable cause, is met by a fine of 10*d.* per quarter hour, and 8*s.* per hour after the first hour.

The work of each machine is measured by a self-acting counter U, Fig. 2, indicating the distance travelled, which is measured at the mean diameter of wear of the rollers; the measurement of distance is taken only during the actual time of work in rolling and in moving from one place of work to another, and an allowance of 3 miles is added for each time of going out to work from the engine house. The total distance travelled by one engine is usually about 15 to 20 miles per day of 10 working hours. The speed of working is from $1\frac{1}{2}$ to $2\frac{1}{2}$ miles per hour, being limited to the latter amount by the public regulations. As a general rule the work is done during the night within the city, and the portion of road repaired during the night is completely finished by the morning ready for traffic. The rate of charge for night work is reckoned from 6 p.m. to 7 a.m. in winter, and from 8 p.m. to 5 a.m. in summer.

In making new roads the broken stone is usually laid down in a single layer of 10 to 12 inches thickness; and this thickness of material can be satisfactorily rolled. In repairing roads the usual practice is to put down a layer of broken stone about $2\frac{1}{2}$ inches thick at the sides of the road and 6 inches thick in the middle, the surface of the road being generally picked up previously. The rolling engine commences work at the side of the road, and travels backwards and forwards over a length of about 100 yards, travelling alternately along opposite sides of the road and working its way gradually to the middle of the road; it then goes forwards to roll another similar length. The layer of broken stones is watered from the street mains, and binding material consisting of road sweepings is put on before the rolling. Not the slightest difficulty is experienced in reversing the motion of the rolling engines, which start in either direction without any slip whatever; and the broken stone is regularly rolled down without getting pushed up or driven before the rollers. The engines start with facility even up a considerable incline; and they turn easily in a circle of only 13 yards radius.

From the experience of the extensive rolling done in Paris with these engines, it appears that the amount of work to be done, or the number of ton-miles of the engine to be paid for in rolling a cubic yard of material, is independent of the thickness of the layer of material to be rolled, when this ranges between 3 inches and 10 inches; and the work required for rolling one cubic yard of material amounts to from 2 to $2\frac{1}{2}$ ton-miles, where the rolling is properly completed. One of the smaller size 15 ton engines therefore, working at the average speed of about $1\frac{2}{3}$ miles an hour, would give 25 ton-miles per hour, and would finish rolling in that time 10 to $12\frac{1}{2}$ cubic yards of material, or 100 to 125 cubic yards per day of 10 working hours. The larger size 30 ton engine would do more than double this amount of work, as its average working speed is about 2 miles per hour.

The materials employed for repairing the roads in Paris are generally very hard, and some of them have very little binding property; a small proportion of the sandy road sweepings is therefore added as a binding material, which is spread over the top of the newly laid stones before the rolling is done. Since the use of the rolling engines has been established however, the proportion of binding material employed has been diminished; and as this material of itself is not favourable to the durability and hardness of the roads, the use of the rolling engines has consequently led to an improvement in the character of the work. The broken stone used for repairs is very hard grit (meulière), or porphyry or trap; it costs when broken from 7*s.* to 15*s.* per cubic yard, being broken uniformly into pieces of about $2\frac{1}{4}$ inches diameter.

In working the steam rollers, two men are employed with the smaller engines, an engineman and a steersman; and with the larger engines there is a fireman in addition, for the purpose of oiling while at work without stopping the engine. The consumption of coal is about 3 to 5 lbs. per ton per mile, being 50 to 80 lbs. per mile for the smaller engines, and 90 to 130 lbs. per mile for the larger ones. The mean power developed by the larger engines in rolling the road is about 20 horse power; it is often below that amount, and then sometimes rises to 30 or even 35 horse power. The machines keep well in order, and run 1200 to 1800 miles before requiring any

important repairs. They are of very strong construction throughout, the axles, chains, pinions, and working gear being made of steel; the engines are made of the quality of best locomotive work, and are consequently expected to keep at work fully ten years.

In reference to the relative cost of rolling roads by the steam rollers or by horse power, the following is a comparison of the prices per ton per mile by each method. The result of numerous data collected of the cost of horse-rolling in Paris, for horse-keep, drivers, and oiling, is 11*d.* per ton per mile: or about $11\frac{3}{4}d.$ including cost of repairs. As these horse-rollers belong to the administration, there is not any charge for interest of capital and depreciation; but the addition of these would make about 14*d.* per ton per mile for the total cost. On the other hand for the steam rolling the actual payment is only half that amount, or 7*d.* per ton per mile, including the contractor's profit; so that there is a great economy in the steam rolling as regards cost of power.

The following calculation affords the means of ascertaining, from the large extent of experience now obtained in the work actually done by these machines, what number of them are required in any particular instance. Supposing the case is taken of a town having 2 million square yards of macadamised road, and that the average annual consumption of materials for road repairs amounts to a thickness of 2 inches over the whole of the road surface, or a total of 100,000 cubic yards per year. The steam rollers of the three sizes in use, weighing in average work 15, 22, and 30 tons, are each found to do an average work of 24, 36, and 48 tons per mile per hour respectively; and when kept at work without useless delays, each machine does per year 250 days' work of 12 hours, or 3,000 hours of work per year; so that the three sizes of machine can do respectively 70,000, 100,000, and 140,000 ton-miles per year. And as the work required for rolling a cubic yard of material has been found to be from 2 to $2\frac{1}{2}$ ton-miles, the total rolling power required for rolling the 100,000 cubic yards of material laid down per year would be from 200,000 to 250,000 ton-miles. Consequently, as each machine of the three sizes can do respectively 70,000,

100,000, and 140,000 ton-miles per year, there would be required for the whole work of the town either 3 to 4 small machines, or 2 to 3 medium machines, or 2 large ones: the choice between these depending mainly upon the local conditions of the work. As an illustration it may be named that in the case of the town of Birmingham the actual amount of the annual work in repairing the roads is about one third of the above quantity, or 34,000 cubic yards of material laid down per year.

In reference to the durability of the roads rolled, as this depends upon the completeness with which the work is done and the weight of roller employed, it follows that the steam-rolled roads are much better finished with the same expense for rolling, and will last much longer on account of the rollers being heavier than horse-rollers. The economy in the road materials is also considerably increased by the broken stones being solidly bedded at once when laid down, instead of being crushed and a considerable percentage wasted in the form of road sweepings by the effects of the traffic passing over the loose stones before they become set.

In conclusion it may be remarked that these steam road rollers are powerful engines from which a large amount of work is obtained at a small cost, when the working of the engine is maintained sufficiently continuous for the interest of the original cost to be spread over a considerable average number of working hours per day. The advantages of the steam rollers over those drawn by horses are, economy in the cost of the work, rapidity of performing it, and greater perfection in the roads rolled: the durability of the road surface being found to be at least doubled when the steam rolling has been well done, as compared with roads not so rolled.

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The Chairman observed that it was a matter of general experience how great a difference there was in riding or driving over a well made road and over a bad road or one on which stones had been newly laid down; and there could be no question as to the desirability of improving the condition of the roads generally in this country. The method now described of applying steam power to the rolling of roads seemed a very simple and complete mechanical arrangement; and the effect of using the steam roller described in the paper must be greatly to improve the state of the roads. One question that occurred to him in connection with the use of any steam road roller was whether the noise made by the working of the roller was likely to frighten horses passing it, as it was often found difficult to get horses to pass a portable engine or traction engine working on ordinary roads.

Mr. Heaton replied that he had seen the steam rollers at work in Paris, and the practice there in the streets where there was great traffic was to work the roller always at night; the road was then stopped up for carriage traffic while the roller was at work, although horses could go by. No objection was experienced in the working of the steam rollers in Paris from risk of accident by frightening horses, and the noise made by the discharge of the exhaust steam was practically drowned by that of rolling the broken stone; the danger of frightening horses was not so great as that arising from the passage of a locomotive engine over an iron viaduct, which was now a matter of common occurrence in large towns. The ordinary practice in repairing roads was that the surface of the road was picked up during the day and the new material laid down ready for rolling, and the rolling was then done during the night, and the next morning the road was quite hard and smooth, ready for traffic again, without any loose stones being left to be crushed by carriage wheels or trodden upon by horses. The size of the stones laid down was strictly limited in Paris to Macadam's rule, not to exceed $2\frac{1}{4}$ inches in the longest diameter; but in Birmingham they were sometimes three or four times that size, as shown by the specimens exhibited which had been picked up in streets under repair. From the experience of the work done by the steam rollers in Paris, it was found that one

such roller would be quite sufficient to perform all the rolling that had to be done in Birmingham, according to the quantity of new material that was at present annually put down in the streets; and assuming that the steam-rolled roads would last twice as long as at present, he had calculated that an annual saving of £5700 to the town would be effected by the use of the steam roller, the present annual expenditure for road material alone amounting to as much as £13,000. Supposing the steam-rolled roads lasted only half as long again as at present, the annual saving would then be £3600; and independent of the increase in the durability of the roads, which must necessarily take place to some important extent, there would still be the great advantage of the continued good surface of the roads for the traffic.

Mr. T. Aveling considered it was not sufficient for a steam road roller to be capable of turning in the circle of 13 yards radius mentioned in the paper, but that it ought to be so constructed as to be able to turn round in less than double its own length. For in the case of rolling a road in which there was both a rising and a descending incline to be traversed, an engine made with the ordinary locomotive construction of boiler and firebox would have to go chimney foremost in going up hill, in order to prevent the top of the firebox from being uncovered by the water; and then on commencing to roll the succeeding descending incline it would have to be turned round, in order to keep the chimney end uppermost in descending the incline, so as still to keep the firebox top covered with water and to prevent priming. It also appeared to him preferable to take off the steam for the cylinders as close to the chimney as possible, in order to ensure always taking it off as dry as possible, since the water would rise at the firebox end when the roller was working on an incline with the chimney end uppermost; and on that account he considered it desirable to place the steam cylinders at the chimney end of the boiler, so as to avoid the condensation which would occur in a long pipe if the steam were taken off close to the chimney and conveyed to cylinders placed at the other end of the boiler. It was also desirable he thought to avoid having so many pinions and spur wheels as were shown in the steam roller now described, for communicating the driving power from the engine to the rollers.

Mr. Heaton said the rollers at work in Paris ran up hill or down hill with either end foremost indifferently, and there was therefore no necessity to provide for turning them in only double their own length. The steam was taken off in a dome on the top of the boiler, and the dome was high enough to ensure the steam being taken off dry under all circumstances. A sufficient height of water level was allowed above the top of the firebox, to prevent any risk of its ever becoming uncovered, even when the roller was working on the extreme incline of 1 in 12 with the firebox end uppermost.

Mr. W. F. Batho considered they were indebted to the writer of the paper for bringing the subject before the meeting; but having had an opportunity of examining the working of the steam rollers in Paris, it appeared to him that the arrangement for turning the machine, by making the pair of long cylindrical rollers converge to the centre of the circle traversed, was complex and not suitable for the heavy work the machine had to do; and in consequence of the rollers being the full width of the machine, a serious grinding action must take place on their surface when out of parallel to each other, which must seriously increase the wear upon them, and would add considerably to the amount of power required to be transmitted through the gearing in driving the machine round a curve. In reference to the mode adopted for driving the rollers by a single pin, so as to allow of their being out of parallel, it was true that by making the parts of steel or case-hardened wrought iron they had been made to work; but the arrangement appeared to him unmechanical and costly, and one in which there must necessarily be great wear and tear. He had himself designed a steam road roller on a different construction several years ago, which was sent out to Calcutta, where it had done good service, having more than earned its entire cost in the economy effected by its use in the repair of the roads. It was made with three rollers, one in front and two behind, the two hind rollers being in line with each other, but on independent axles, and each driven by a pitch chain; and the front roller, which was made a little wider than the space between the two hind rollers, was carried in a turntable resting on friction wheels, for guiding the machine: the weight was

distributed uniformly over the whole width of the machine, each roller carrying a load proportionate to its width. The three-roller type of machine he considered was preferable to one having two long rollers, especially if provision were made for driving each of the three rollers, and for disengaging either of the two hind rollers at pleasure, for the purpose of turning or guiding the machine.

Mr. Brooke Smith considered the rolling of roads was a subject of great importance to the country at large, and thought it was most desirable that a steam roller should be adopted for the roads in Birmingham; but as there was evidently a difference of opinion respecting the most advantageous construction of rollers for the purpose, it was very important to ascertain the best principle on which a steam road roller should be made so as to do its work in the most efficient manner and at a reasonable cost. Another important requirement in connection with the repair of roads was a more perfect way of breaking the stones preparatory to their being laid on the road, as this was ordinarily neglected to a very serious extent, and large irregular shaped stones were constantly laid down, instead of the small regular stones broken according to Macadam's rule, which alone could make a sound and durable road.

The Chairman mentioned that he had seen in London a steam road roller at work in Hyde Park, and he enquired how that roller was found to answer.

Mr. E. A. Cowper said he had seen the steam roller referred to, and it was one designed by Mr. David Thomson and constructed by Messrs. Moreland of London, having a single large roller extending the entire width of the machine and driven by gearing from a pair of vertical cylinders fixed at the back of the machine and supplied with steam by a vertical boiler; the weight of the machine was about 24 tons, and there was a wheel in front to steer by. The same objection however that had been mentioned in regard to the Paris rollers was experienced also in this case, from the difficulty of turning the machine with a long roller extending the whole width; and it would probably not turn in anything less than the circle of 13 yards radius required by the Paris rollers. In attempting to turn it too rapidly he had seen the front wheel pushed

along obliquely and sliding on the ground, without producing its intended effect of guiding the machine in turning; the steering was indeed at all times so imperfectly controlled by the front wheel that great caution was required in guiding the machine round very sharp corners, in order to avoid running against the lamp posts. There could be no question however as to the excellence of the work done by the heavy steam roller, which had the effect of turning down the sharp edges of the stones and leaving their flat sides uppermost, bedding the stones together in the road so as to make a solid level surface, and leaving the road in beautiful condition for the traffic, like the excellent roads that were seen throughout Paris at the present time. The steam roller not only made a better road, but its employment was decidedly economical in the cost of maintaining the roads.

Mr. J. Manning observed that every one visiting Paris must be struck by the excellent condition in which the roads were kept there; and as it appeared from the particulars given in the paper that by the use of the steam rollers the local authorities saved themselves all the trouble and half the cost of rolling the roads, in comparison with the horse-rolling previously employed, he thought the steam road rollers ought to come into more general use. He had seen the rollers at work in Paris, and their effect upon the road was just what had been described, turning the stones over so as to bring the flat faces uppermost, and preventing the sharp edges of the stones from standing up in the surface of the road. The efficiency of the process was so complete that a length of road newly laid one day with fresh stones and then rolled during the night was finished so effectually by the following morning as to present no appearance of having been so recently repaired. The value of these rollers appeared to him so great that his firm had decided upon making one of them, with a view to their introduction into this country; for although a few steam road rollers had been used here already, they had in all cases been made with only one driving axle, whereby a considerable portion of the weight of the machine was lost for the purpose of driving adhesion. This appeared to him to be a mistake, and to be the cause of the difficulty that had been mentioned in

turning the long driving roller by means of a steering wheel in front; but that difficulty was entirely obviated by the plan now described of having two driving rollers and making them converge to the centre of the circle to be traversed. Moreover in rollers which did not make use of the whole weight of the machine for driving adhesion, it occasionally happened that there was a difficulty in starting, in consequence of the driving roller slipping in its attempt to mount the stones in front of it, which caused both the driving roller itself and the front carrying roller to work themselves into a deeper and deeper hollow in the endeavour to start, so that the longer they were in starting the greater was the difficulty in getting them to move; but the Paris rollers, having the whole of their weight utilised for driving adhesion, were found to start at once in either direction without any hesitation, and therefore without ever working themselves into a hollow; and as both the rollers were driven, there was no liability of one of them roughing up the road in consequence of the whole work of guiding the machine being thrown upon it alone. The additional mechanism required to obtain these results appeared to him therefore to be quite justified by the advantages gained; and if in the course of further experience it were found that any simplification of the construction could be effected, that would be a further improvement; meanwhile the very advantageous employment of the steam road rollers in Paris at the present time might be a sufficiently satisfactory ground for their adoption elsewhere.

Mr. W. Rolason enquired whether the street sweepings used in Paris as a binding material for the newly laid stones were placed on the top of the stones or underneath them.

Mr. Heaton replied that the binding material was spread over the surface of the newly laid stones after they were put down but before the rolling was done; and the roller then consolidated the whole into a hard and even metalling.

Mr. E. A. Cowper suggested that the objection of the grinding action occurring in turning long rollers round a curve might be obviated by cutting each long roller into several short ones, the middle roller alone being driven, and the outside ones running loose

upon the same shaft, which would keep them all in a straight line while allowing of turning a sharp corner with facility.

Mr. T. Aveling observed that in the case of a roller extending the whole width of the machine and made all in one piece, if there happened to be a soft or hollow place in the road in any part of that width, the roller in passing over it would bear upon the high places on each side, and would leave the soft place not properly rolled; and the defect would not be seen till it was found out by the traffic, and then the road would be liable to wear in holes. A roller therefore to be efficient ought to be composed he considered of several rings or rollers, so far moveable relatively to one another that if any one of them passed over a hole or a soft place in the road it should drop and press the road in that soft part or hollow, so that the hollow might be seen and more material laid down there to bring it up level; but with a long roller all in one piece he thought it would not be practicable to get a good road. In the steam road rollers made by his own firm there were two driving rollers in front, one on each side, each roller being rather longer than one quarter the width of the machine; and a steering roller behind, carried in a swivelling frame and made in two separate portions, for rolling the intervening width between the front rollers. The two driving rollers were driven separately by gearing from the engine, so that by driving the roller on one side only and disconnecting that on the opposite side the machine could be turned completely round in only double its own length, turning upon the disconnected roller as a pivot; and the machine was thus capable of turning round any corner.

The Chairman enquired how much of the weight was available for driving in those rollers, and whether they always went in one direction only; and he asked how many steam road rollers were in use at the present time in this country.

Mr. T. Aveling replied that the weight of the machine was equally divided between the front and hind rollers, so as to give a uniform rolling weight across the entire width of road rolled by the machine, and half the total weight was therefore available for driving. The rollers worked in either direction along level roads, but in going up hill it was best to go with the chimney first in order to prevent

the risk of the firebox top getting uncovered by the water; and that was the reason why the roller was arranged for turning in only double its own length. Two of these rollers were at present at work in this country, one in Liverpool and one in Sheffield; and ten more on the same plan had been sent abroad. The Liverpool roller had been at work two years and was 30 tons weight, the driving rollers being 7 feet diameter and the steering rollers 5 feet diameter, and the total width was 9 feet; the Sheffield roller weighed 25 tons and had been one year at work, the total width being 7 feet, the driving rollers 6 feet diameter and the steering rollers the same. These two rollers with the other one in London that had been referred to were the only steam road rollers at present working in this country.

Mr. E. A. Cowper enquired whether the rollers were ever found to drive the stones up in front of them, instead of rolling them down.

Mr. T. Aveling said that depended upon the diameter of the rollers and the weight of the machine. The size of the machine that had been most in demand had the driving rollers 5 feet diameter and steering rollers 4 ft. 9 ins., and weighed 15 tons, giving $7\frac{1}{2}$ tons on each pair of rollers; and these machines worked up an incline of 1 in 12 without driving the stones up in front of the rollers. The 30 ton Liverpool roller was too heavy he thought, and the width of 9 feet too great; and he considered 15 tons weight was quite sufficient for a road roller, and 6 feet width.

Mr. Heaton enquired whether the driving rollers were not found to slip in starting, in consequence of only half the weight being available for driving adhesion; and he asked what was the ordinary speed in working and the expense.

Mr. T. Aveling replied that the driving rollers did not slip in starting, when the machine was started quietly, but if it was started too quick they would of course slip, as was the case with locomotives in starting a railway train. The speed of the steam road rollers in working was $1\frac{1}{2}$ miles per hour, and the working expenses were 20*s.* per day, so that the rolling was done cheaper by steam power than by a roller drawn by four horses.

The Chairman observed that, with only three steam rollers for roads at present at work in this country, it was evident that there was a fine field for the application of steam power to the purpose, and for economy in the maintenance of roads, inasmuch as it appeared the cost of rolling the roads in Paris was now reduced one half by the employment of the steam road rollers.

He moved a vote of thanks to M. Gellerat and Mr. Heaton for the paper, which was passed.

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The Meeting then terminated.

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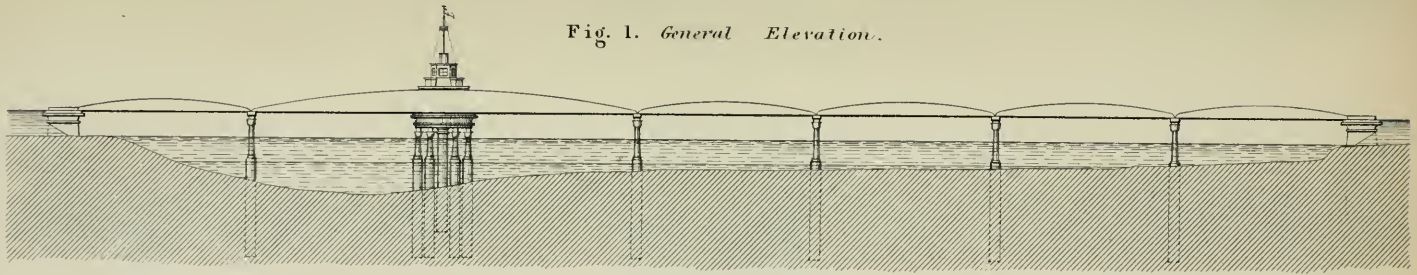
# OUSE SWING BRIDGE.

*Plate 17.*

Fig. 1. *General Elevation.*



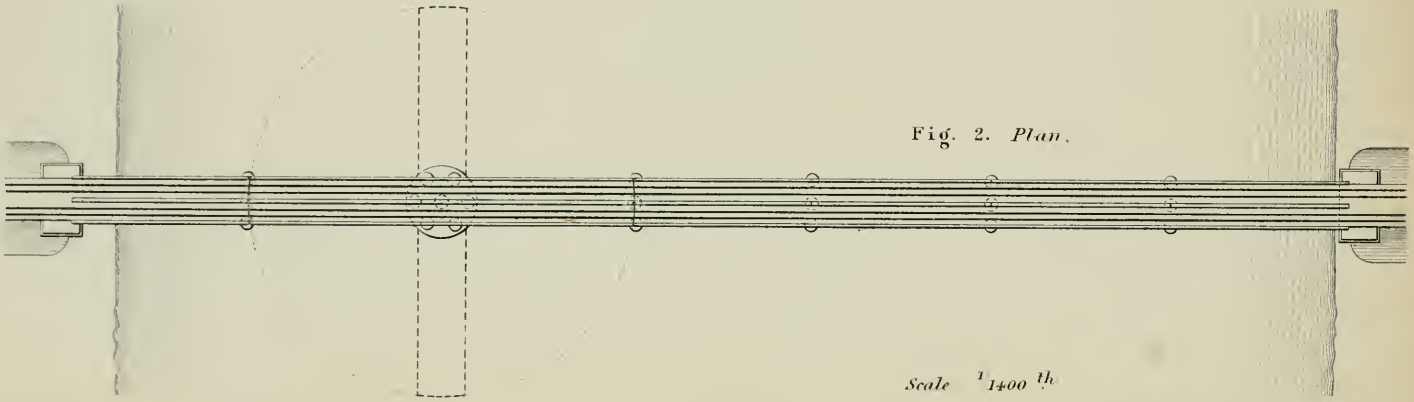


Fig. 2. *Plan.*

*Scale* $\frac{1}{1400}$ *th*

100 50 0 100 200 300 Feet.

*(Proceedings Inst. M.E. 1869.)*

# OUSE SWING BRIDGE.

*Plate 18.*

*Swinging Portion.*

Fig. 3. *Elevation.*

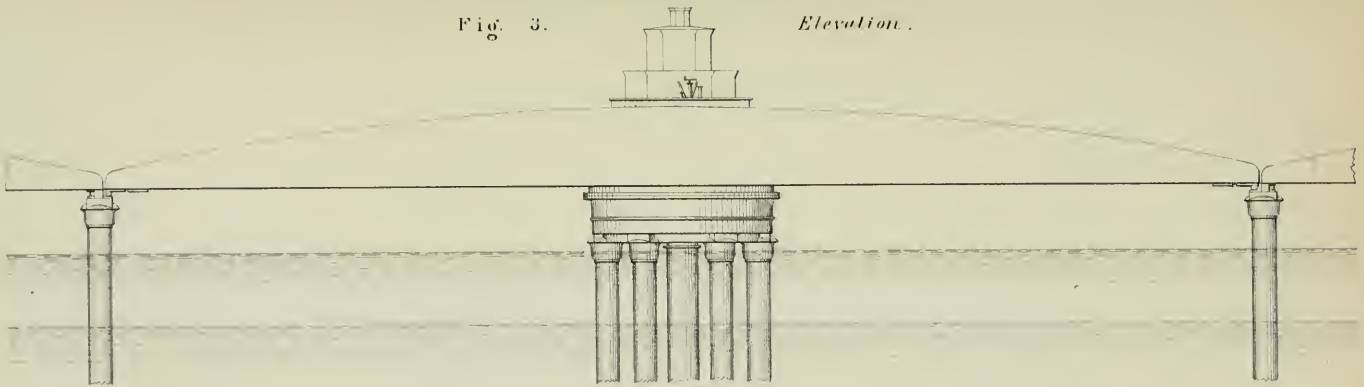
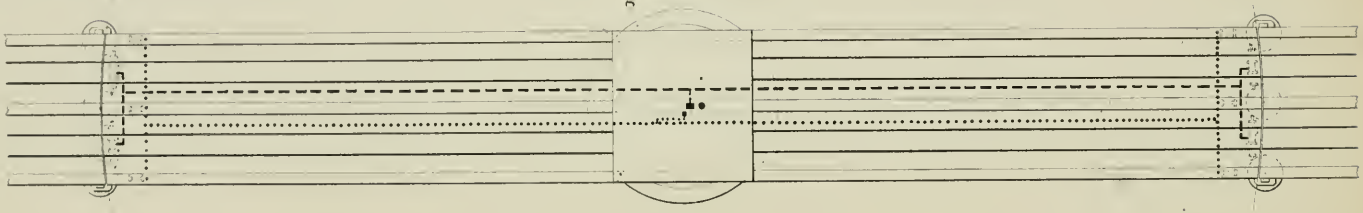
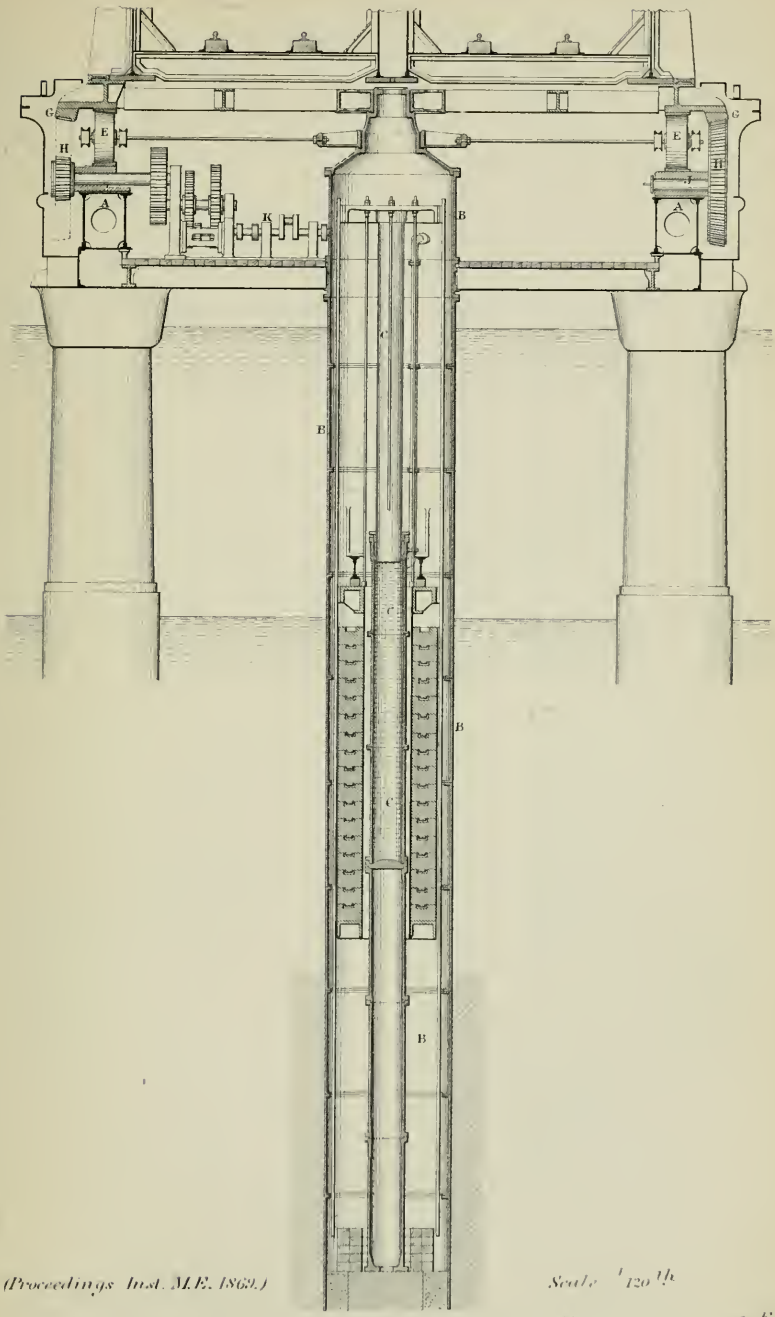


Fig. 4. *Plan.*



*(Proceedings Inst M E 1869.)* *Scale $\frac{1}{480}$th.* 0 50 100 150 Feet.

Fig. 5. *Section of Centre Pier and Engine Room.*




*(Proceedings Inst. M.E. 1869.)*

*Scale* 1/120 *th*

Fig. 6. *Plan of Roller Frame and Rollers in Centre Pier.*

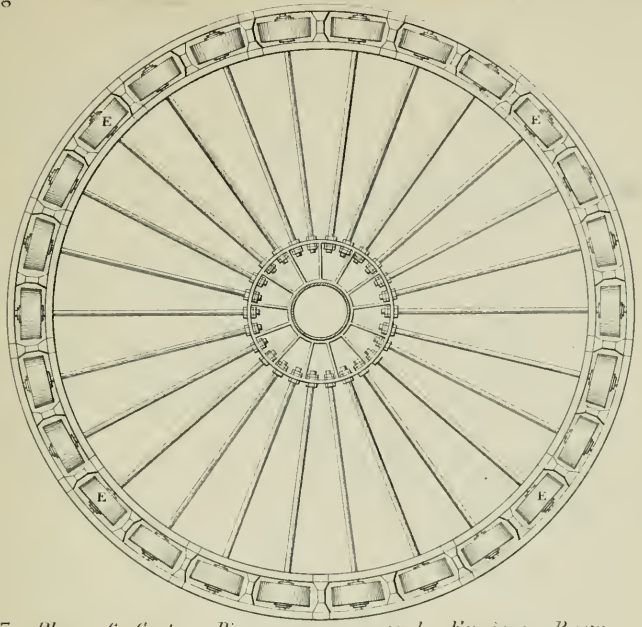
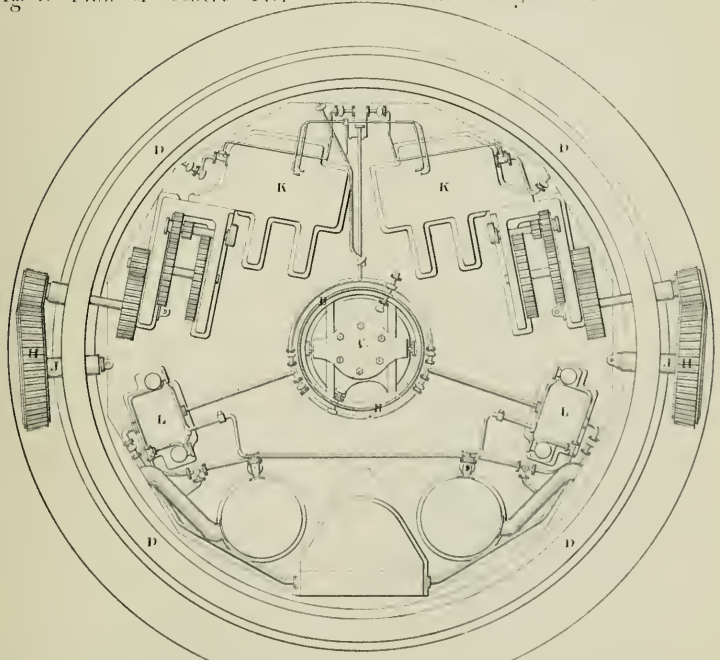



Fig. 7. *Plan of Centre Pier and Engine Room.*




*(Proceedings Inst. M.E. 1869.)* *Scale* 1/120th

10 5 0 10 20 30 Feet.

# OUSE SWING BRIDGE.

*Plate 21.*

Fig. 8. *Enlarged Section of Engine Room.*

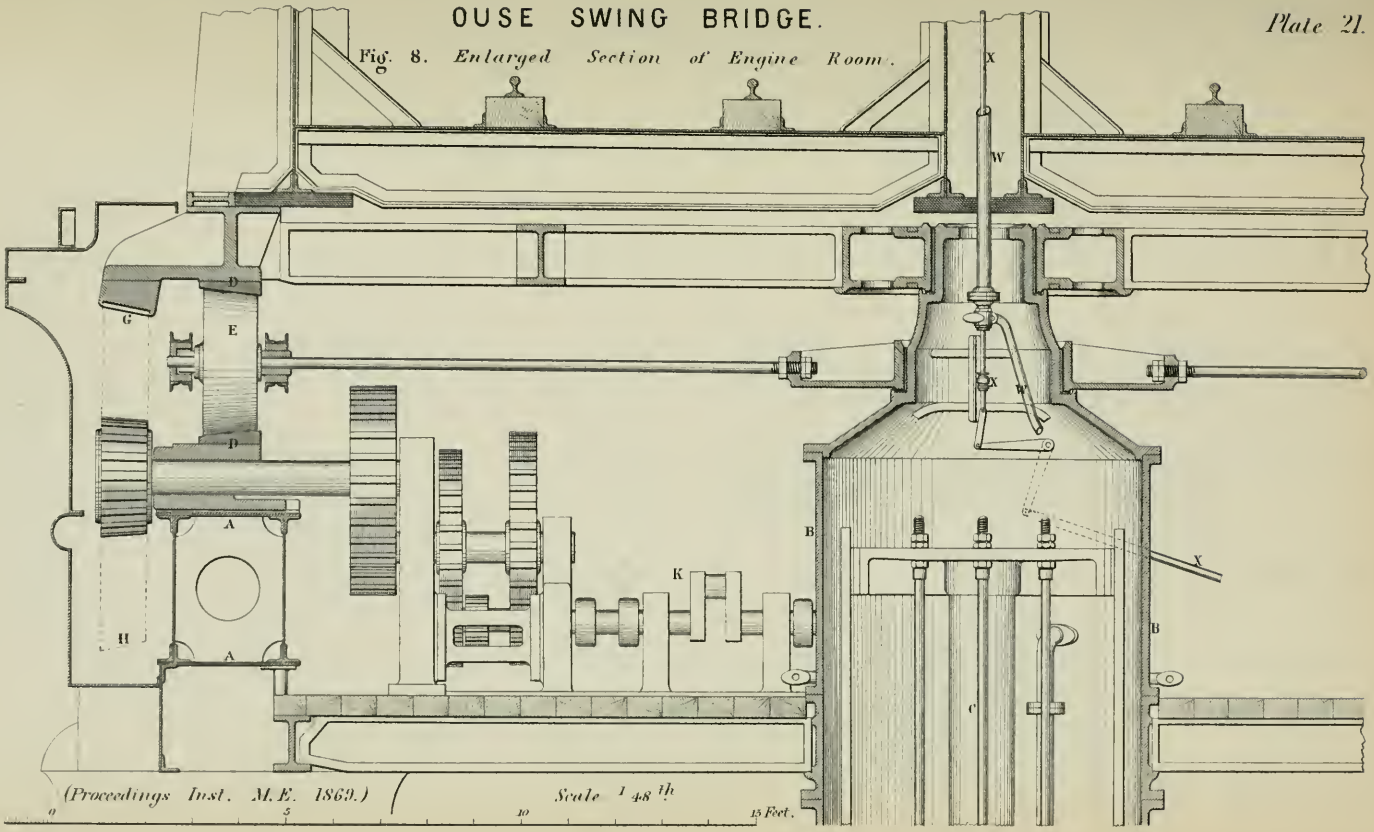
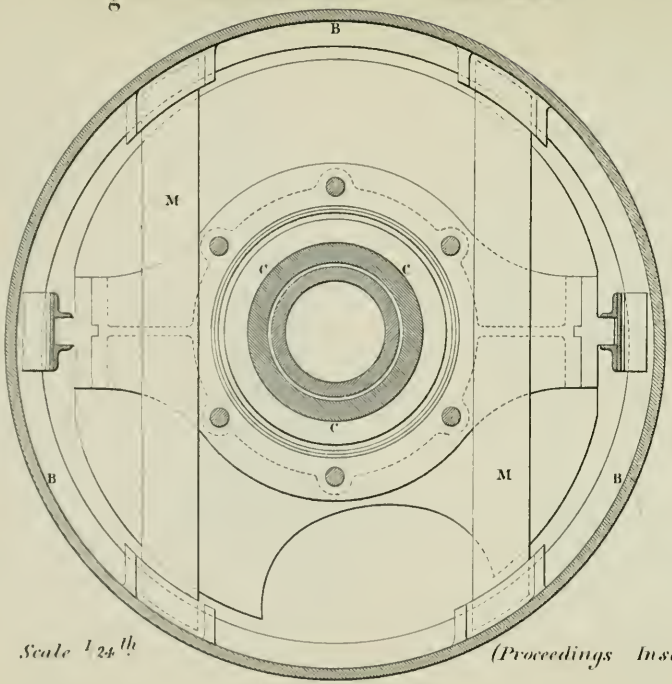


Fig. 9. *Sectional Plan of Accumulator.*

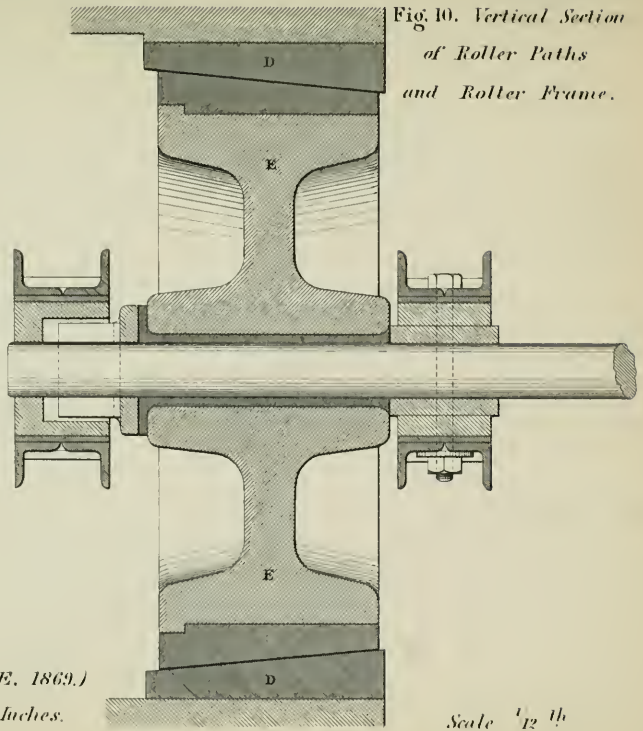



*Scale* $\frac{1}{24}$ *th*

*(Proceedings Inst. M.E. 1869.)*

10 5 0 10 20 30 40 50 60 70 80 *Inches.*

Fig. 10. *Vertical Section of Roller Paths and Roller Frame.*




*Scale* $\frac{1}{12}$ *th*

Fig. 11. *Plan of Hydraulic Engines.*

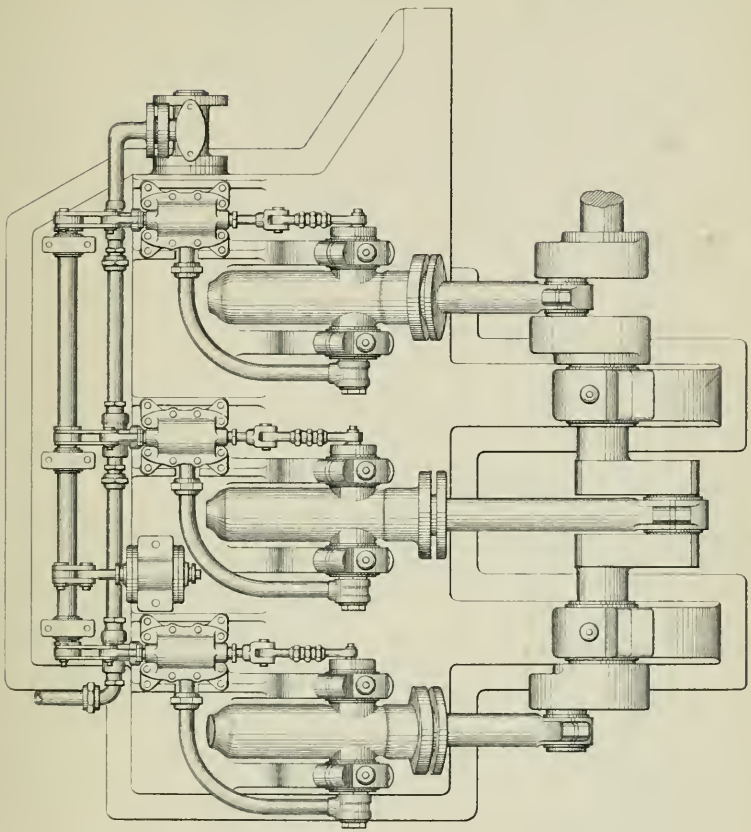
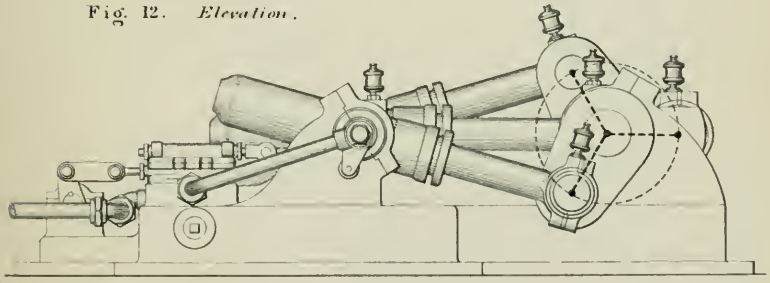


Fig. 12. *Elevation.*



*(Proceedings Inst. M.E. 1869.)* *Scale* $\frac{1}{24}^{th}$

10 5 0 10 20 30 40 50 60 70 *Inches.*

# OUSE SWING BRIDGE.

*Locking Gear &c. at Ends of Bridge.*

Fig. 13. *Plan of Bridge End showing Locking Bolt and Lifting Gear.*

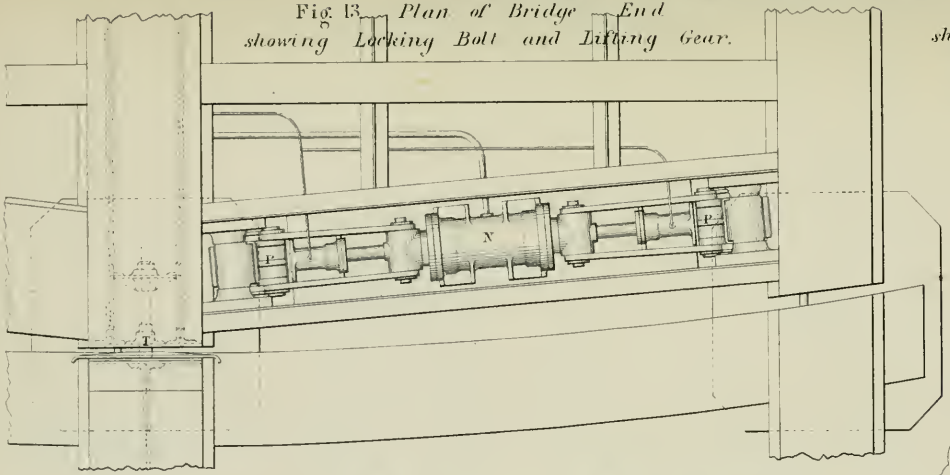



Fig. 15. *Longitudinal Section showing Locking Bolt and Resting Block.*

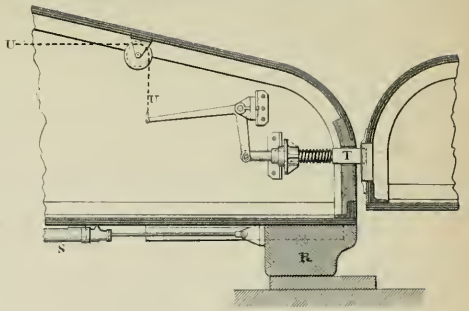
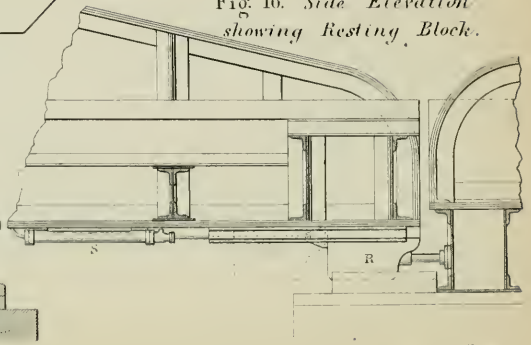



Fig. 16. *Side Elevation showing Resting Block.*



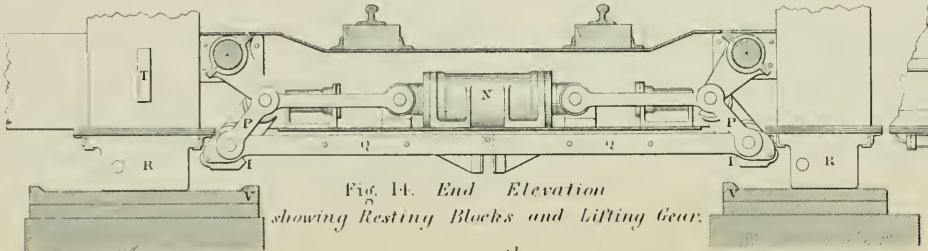




Fig. 14. *End Elevation showing Resting Blocks and Lifting Gear.*

*(Proceedings Inst. M. E. 1869.)* *Scale* $\frac{1}{48}$ *th*

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

*Guibal Ventilator 36 feet diameter at Thrislington Colliery.*

Fig. 1. *Longitudinal Section.*

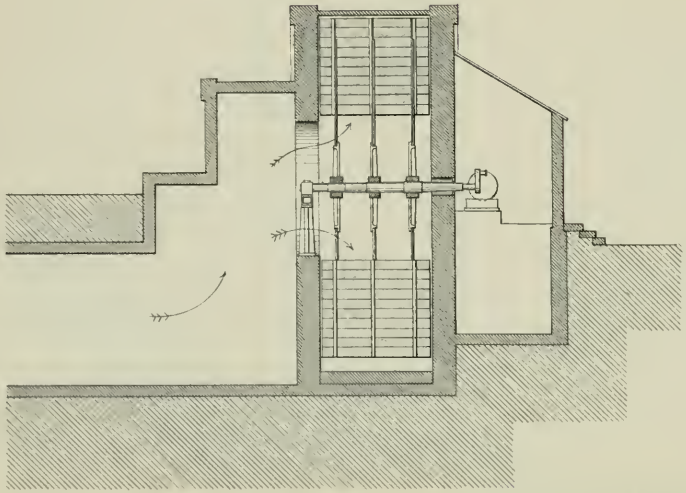
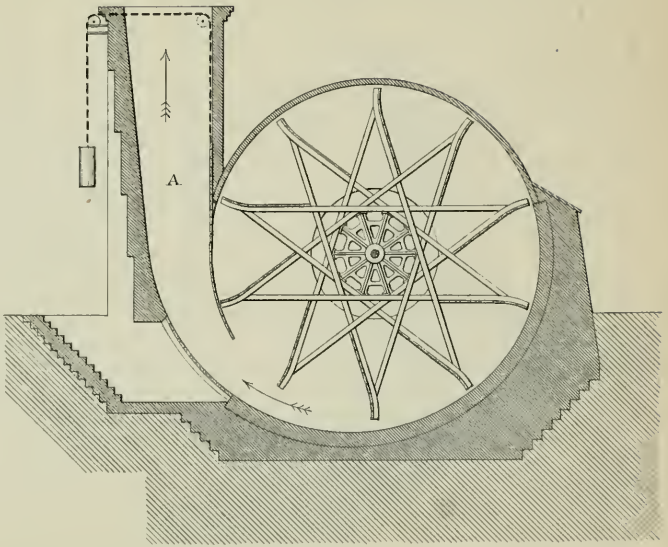
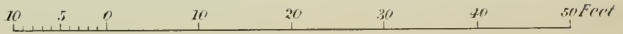


Fig. 2. *Side Elevation of Fan.*




*(Proceedings Inst. M.E. 1869.)*

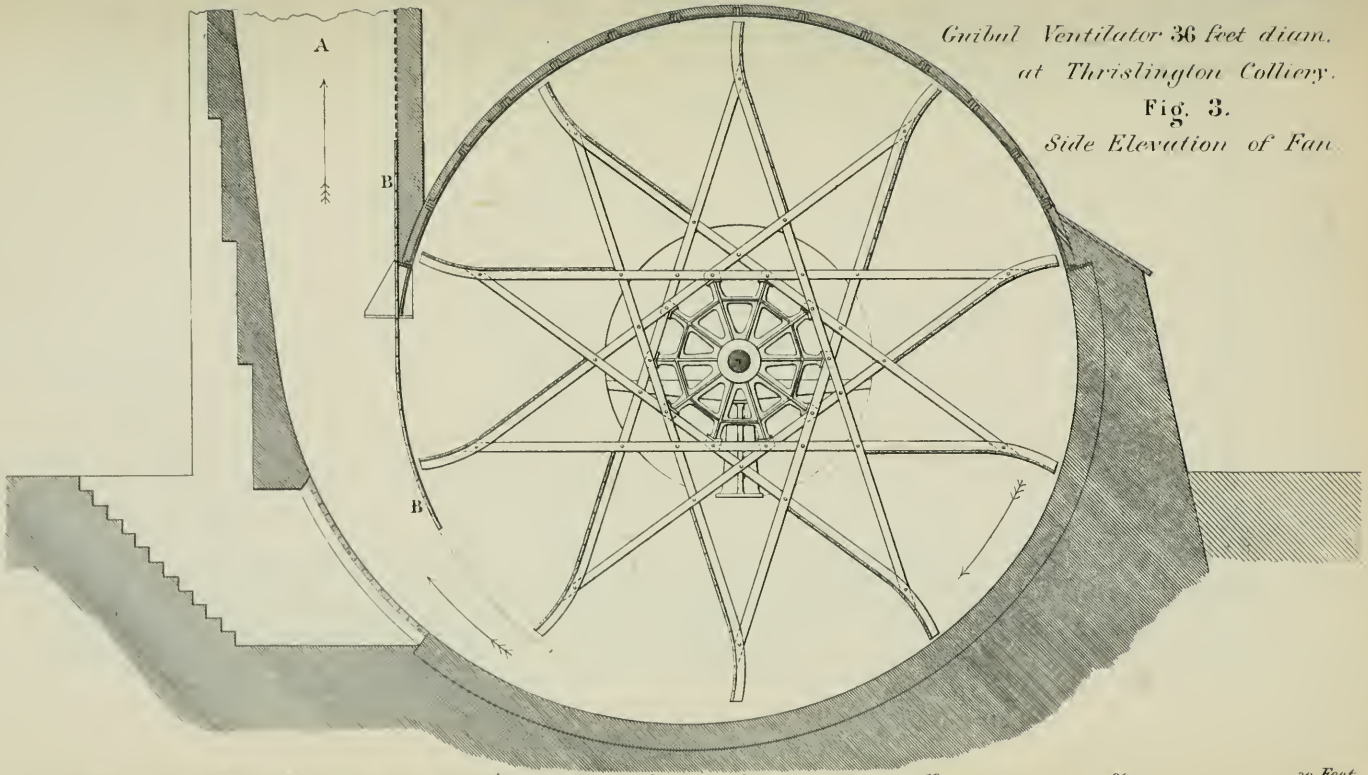
*Scale* $\frac{1}{240}^{th}$.



*Guibal Ventilator 36 feet diam. at Thrislington Colliery.*

Fig. 3.

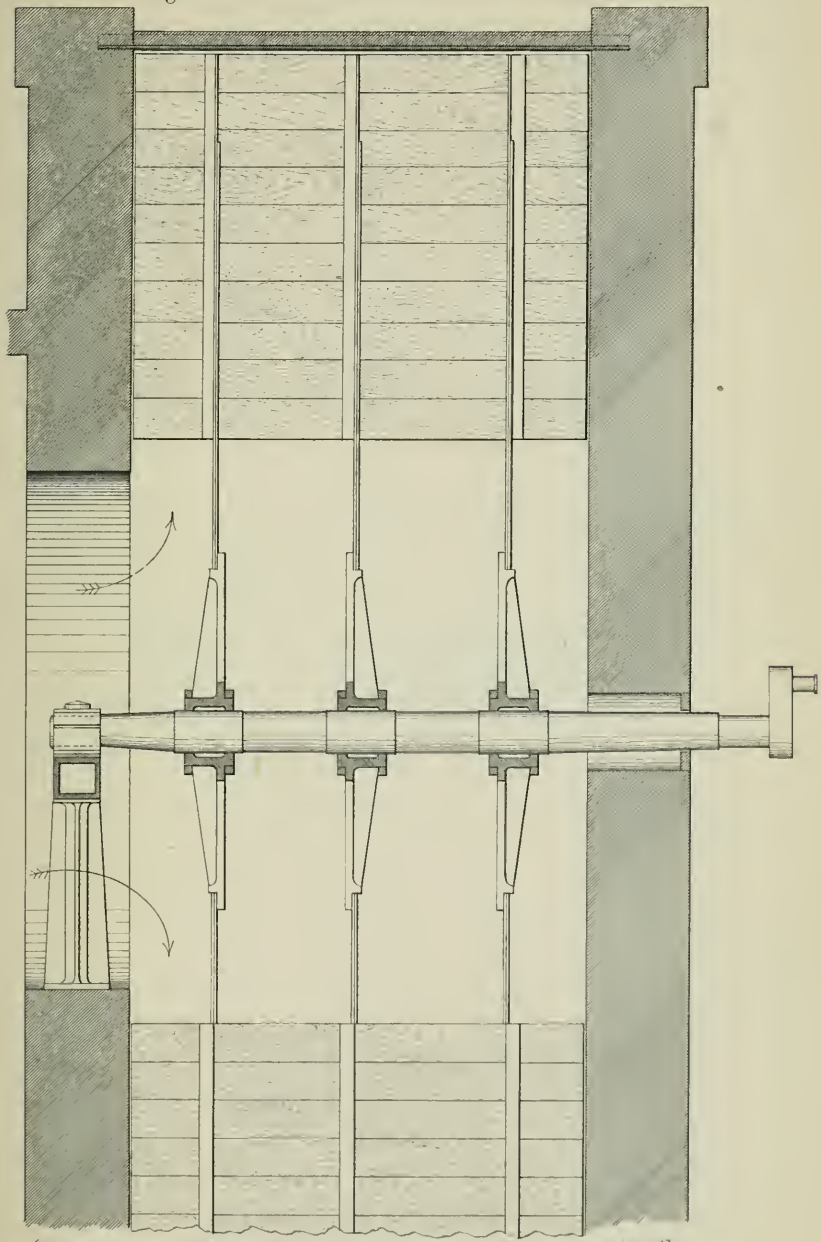
*Side Elevation of Fan.*




*(Proceedings Inst. M.E. 1869.)* *Scale* 1 120th

*Guibal Ventilator 36 feet diam. at Thrislington Colliery.*

Fig. 4. *Longitudinal Section.*



*(Proceedings Inst. M.E. 1869.)* *Scale 1/60*

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 Feet.

*Biram Ventilator* $22\frac{1}{2}$ *feet diam. at Elsecar Colliery.*

Fig. 5.

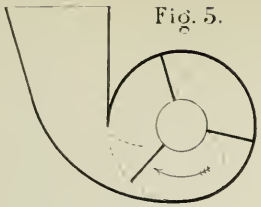


Fig. 6.

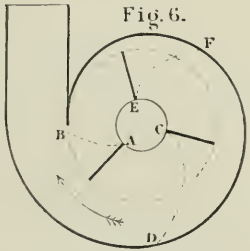



Fig. 7.

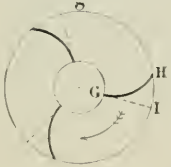
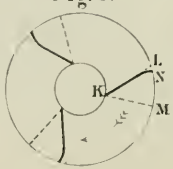



Fig. 8.




*(Proceedings Inst. M.E. 1869.)*

Fig. 9. *Longitudinal Section.*

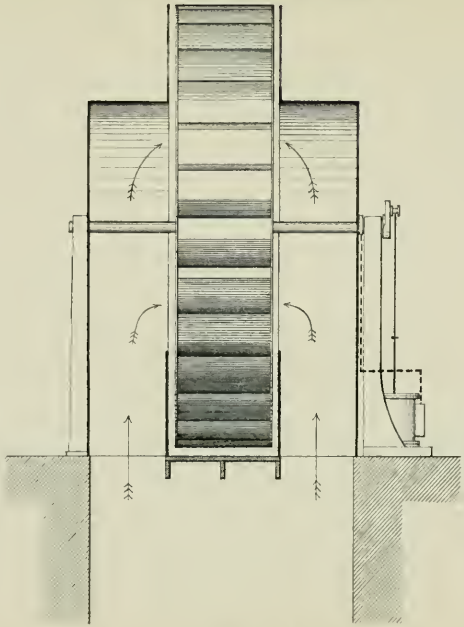
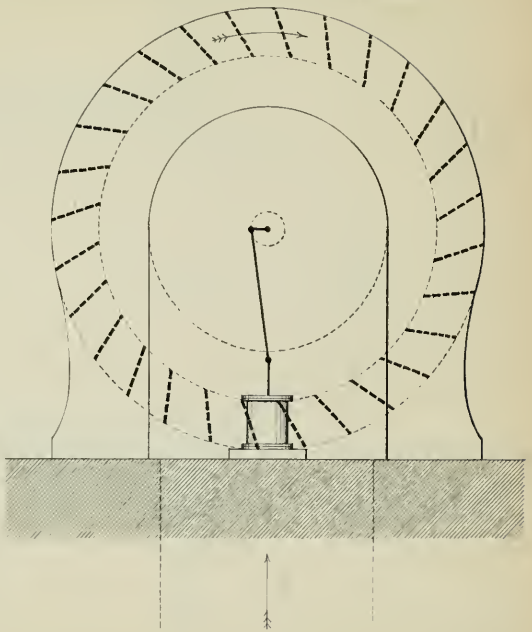


Fig. 10. *Side Elevation.*



*Scale* $\frac{1}{120}$*th*

10 5 0 10 20 Feet.

*Brunton's Ventilator, 20 feet diam.,*
*at Cwmsaerbran Colliery, South Wales, 1855.*

Fig.11. *Vertical Section.*

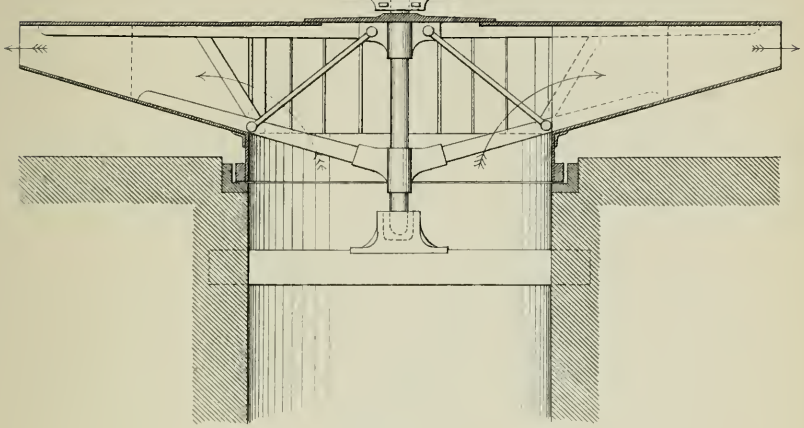
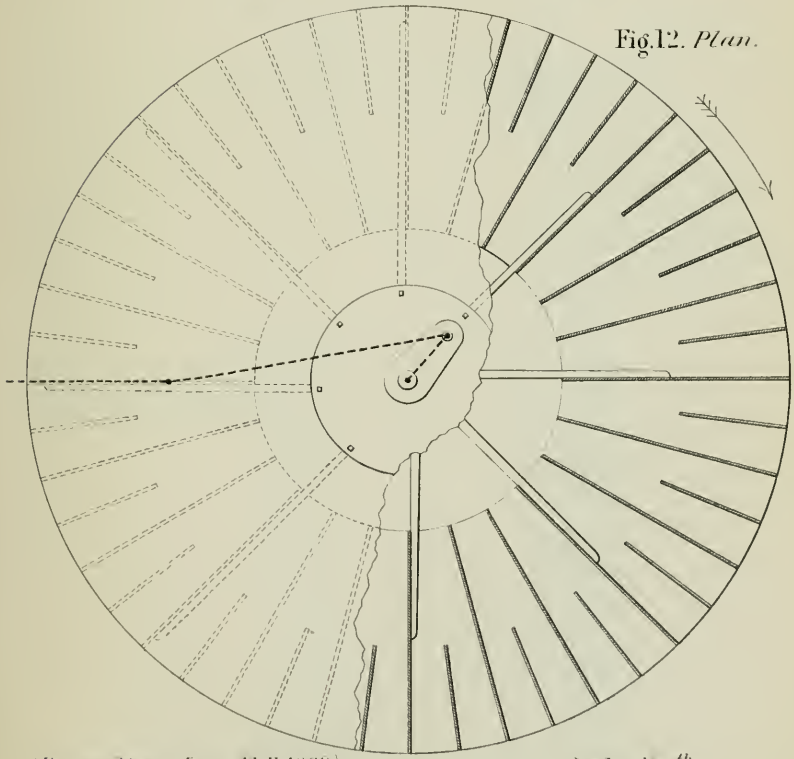


Fig.12. *Plan.*

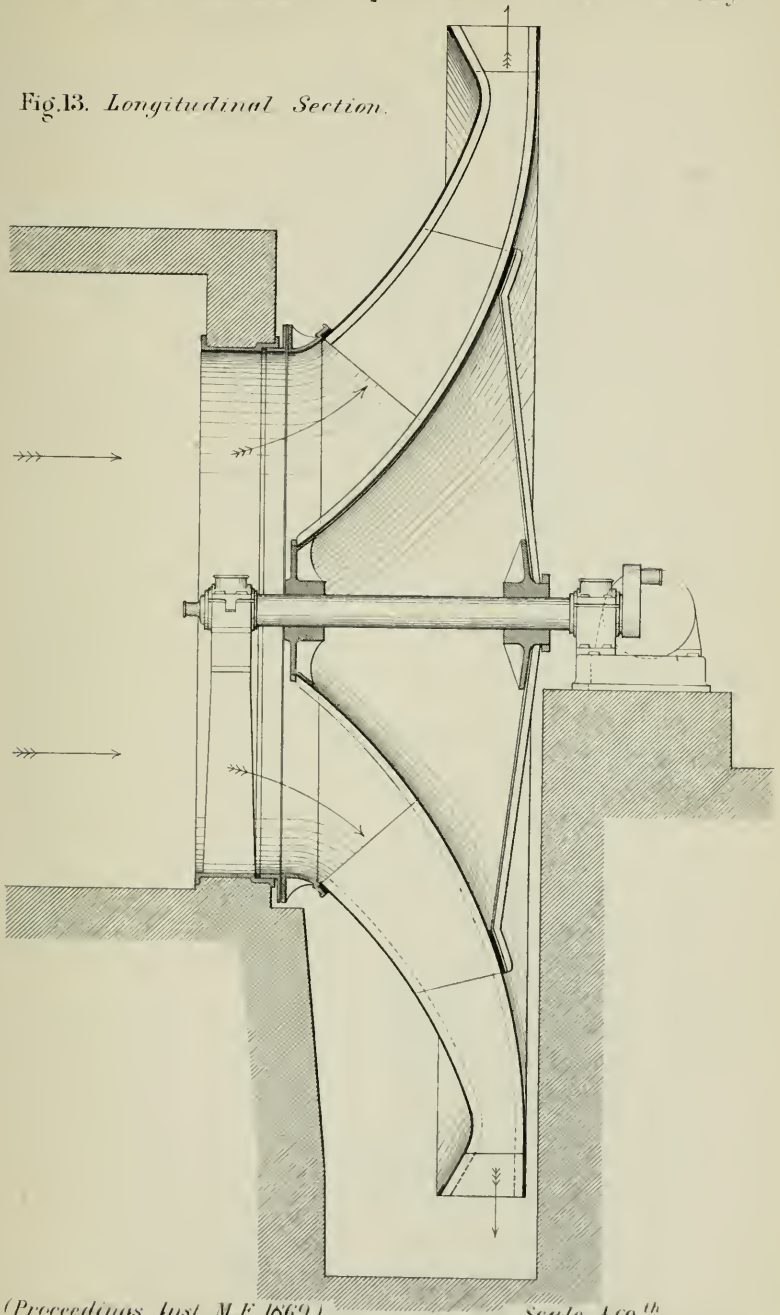


*(Proceedings Inst. M.E. 1869)* *Scale* 1/60th

0 5 10 15 Feet

*Waddle Ventilator 31½ feet diam. at Pelton Colliery.*

Fig. 13. *Longitudinal Section.*



*(Proceedings Inst. M.E. 1869.)*

*Scale 1/60th*

0 5 10 15 Feet.

*Waddle Ventilator 31½ feet diameter at Pelton Colliery.*

Fig.14. *Front Elevation.*

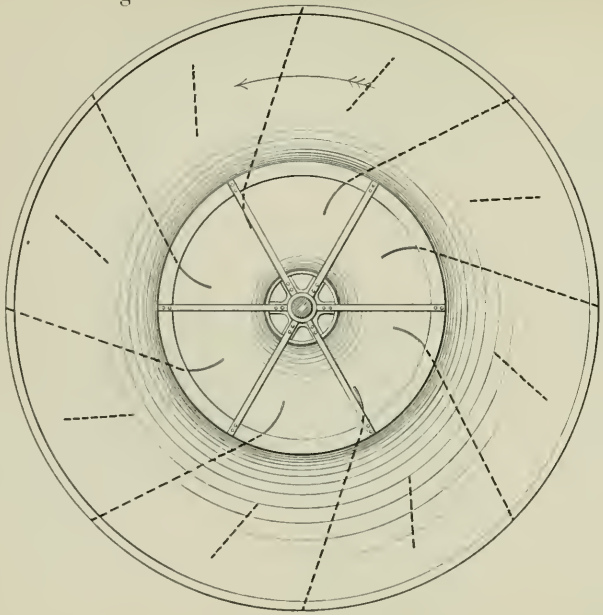
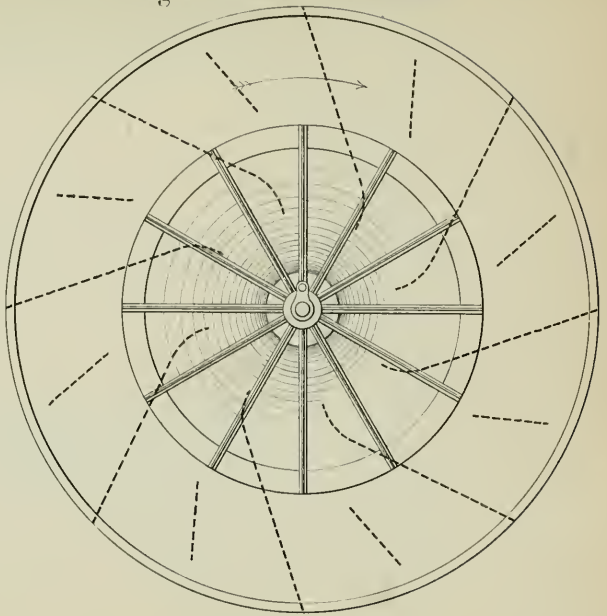


Fig.15. *Back Elevation.*

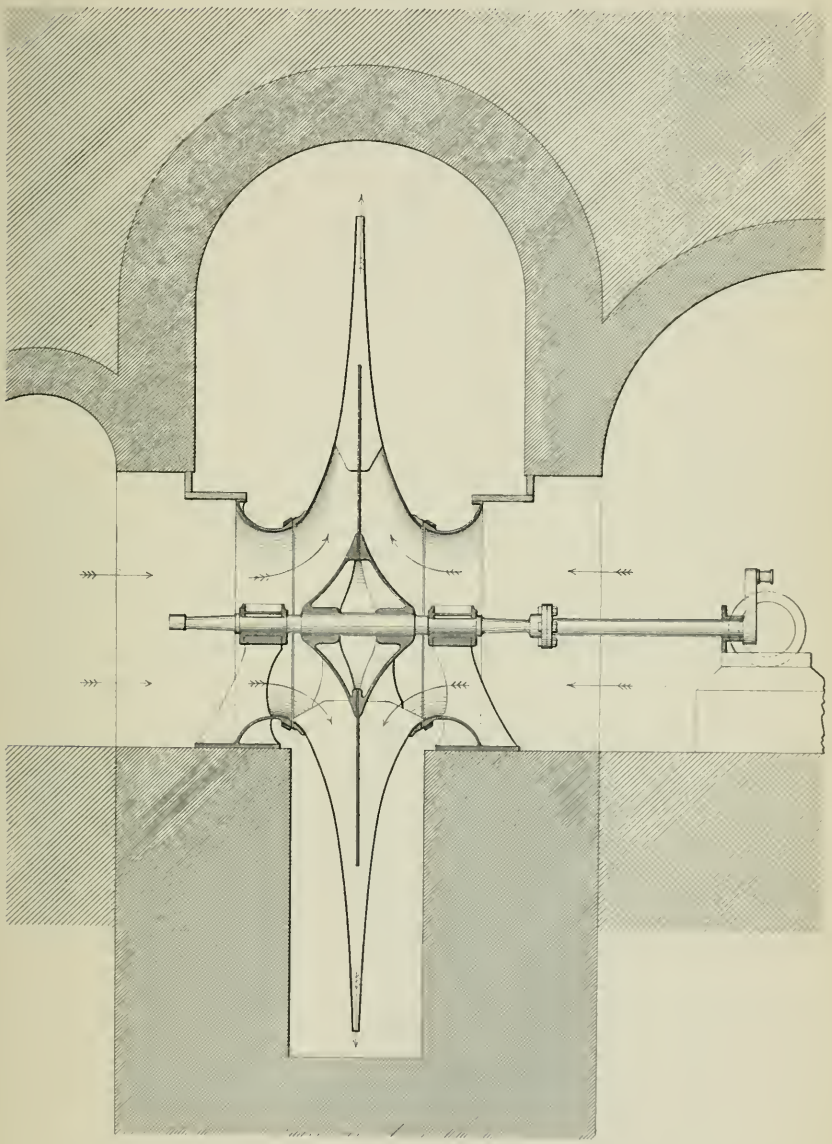


*(Proceedings Inst. M E 1869)* *Scale 1/120th*

10 5 0 10 20 30 Feet

*Rammell Ventilator 22 feet diam. at Framwellgate Colliery.*

Fig. 16. *Longitudinal Section.*



*(Proceedings Inst. M.E. 1869.)*

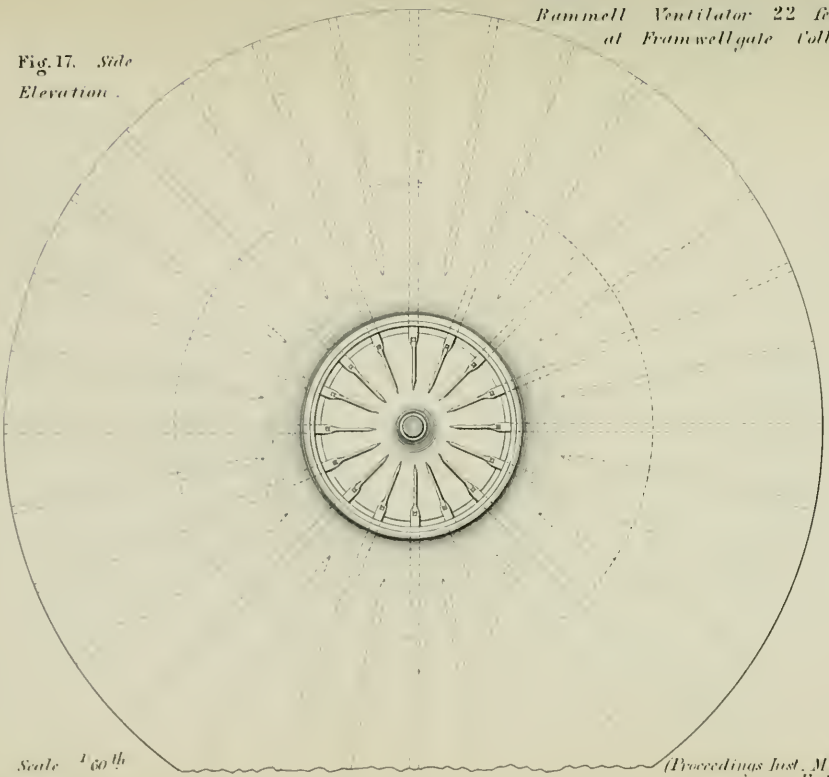
Scale $\frac{1}{60}$ th

0 5 10 15 Feet.

# MINE VENTILATION.

*Rammell Ventilator 22 feet diam. at Framwellgate Colliery.*

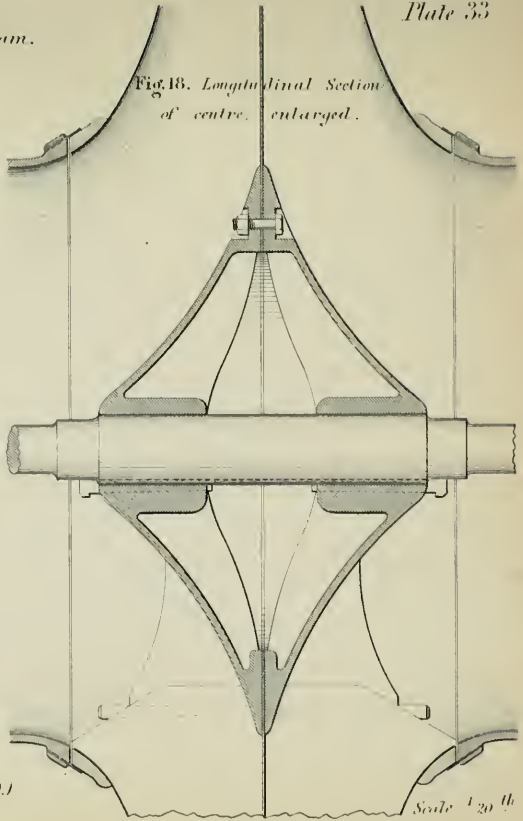
Fig. 17. *Side Elevation.*



Scale $\frac{1}{60}$th

0 5 10 15 20 Feet.

Fig. 18. *Longitudinal Section of centre, enlarged.*

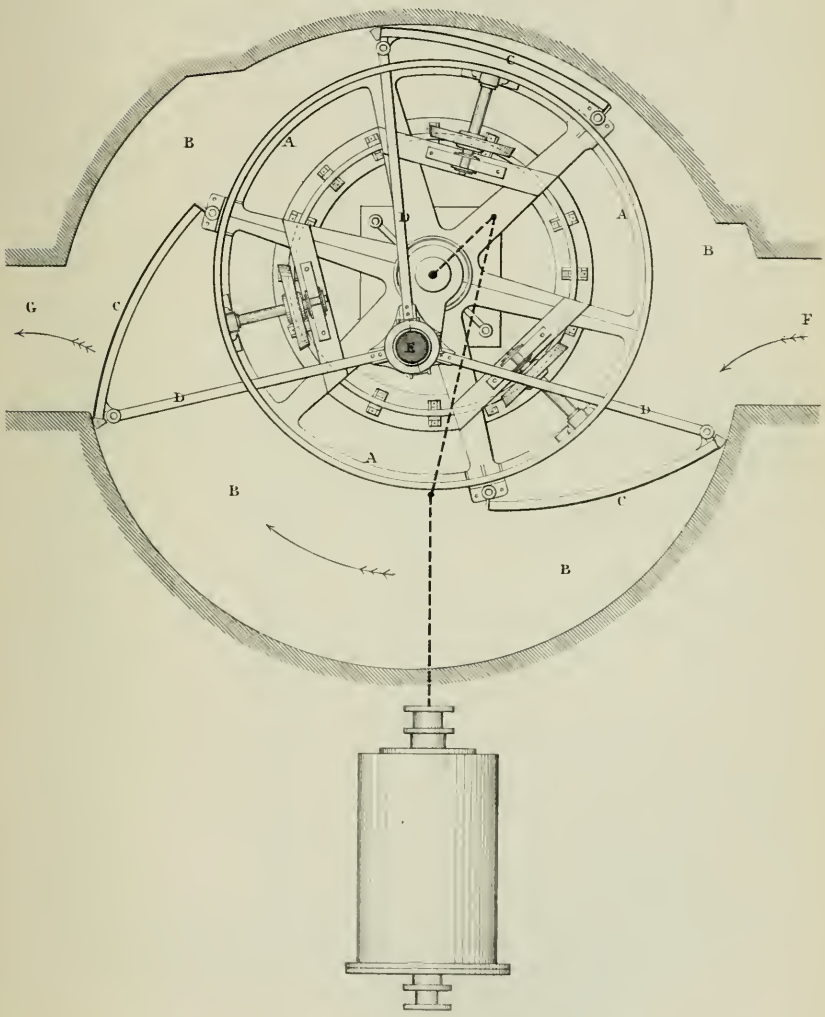


Scale $\frac{1}{20}$th

(Proceedings Inst. M.E. 1869.)

*Lemielle Ventilator 23 ft. diam. and 32 ft. height at Page Bank Colliery, South Branepeth.*

Fig. 19. *Sectional Plan*

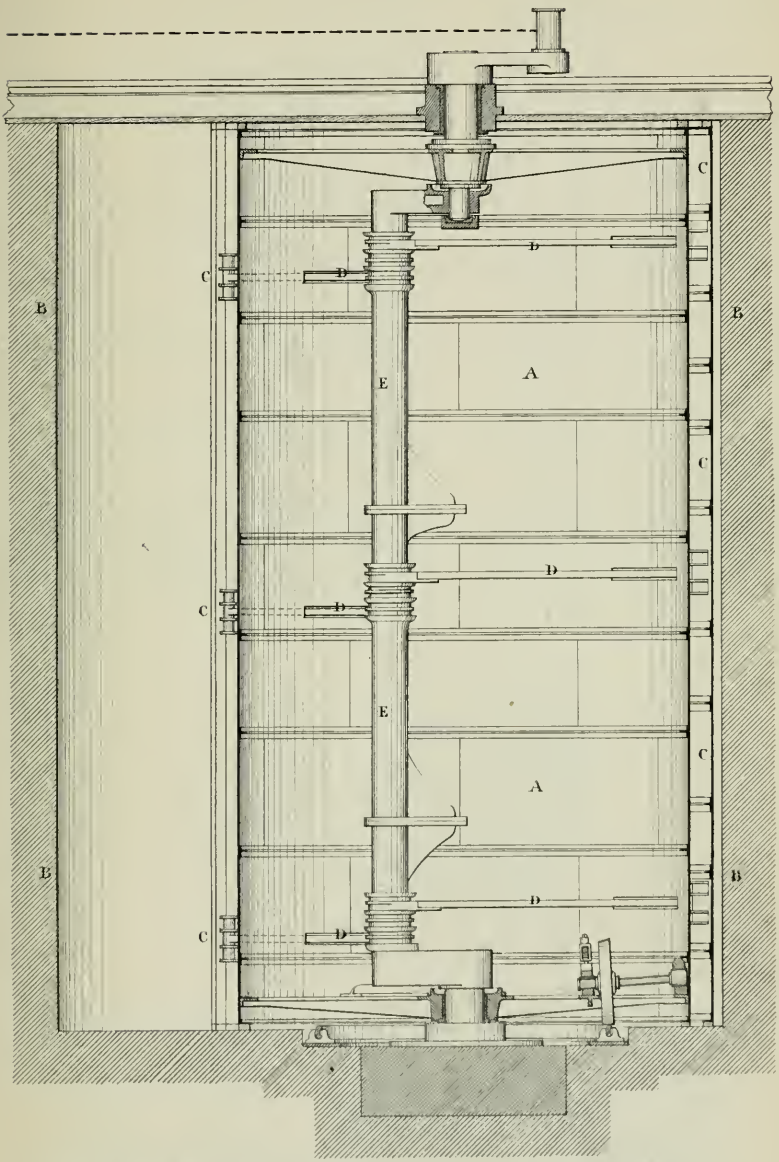



*(Proceedings Inst. M.E. 1869.)* *Scale 1/80th*

0 5 10 15 20 25 Feet

*Lemielle Ventilator at Page Bank Colliery.*

Fig. 20. *Vertical Section.*




*(Proceedings Inst. M.E. 1869.)*

*Scale 1/80th*

0 5 10 15 20 25 Feet.

*Boilers at Rainton Colliery.*

Fig 1. *Longitudinal Section.*

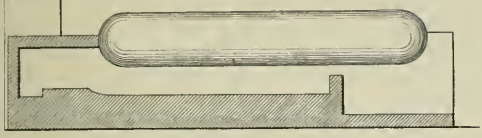
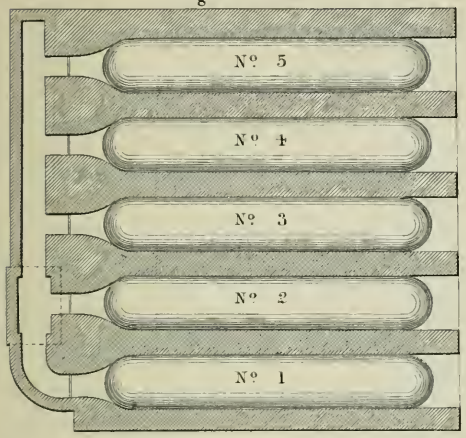
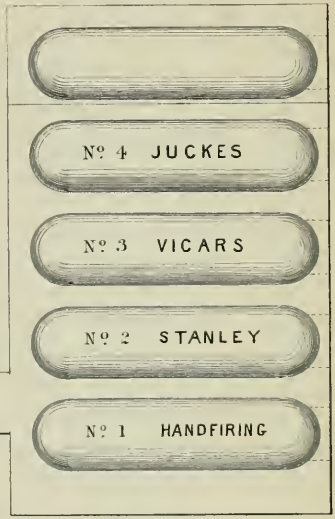


Fig. 2. *Plan.*




*Boilers at Seaham Colliery.*

Fig. 3. *Plan.*




Scale 1/250th 10 5 0 10 20 30 40 50 60 Feet.

*Boilers at Silksworth Colliery.*

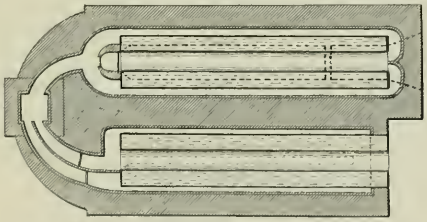
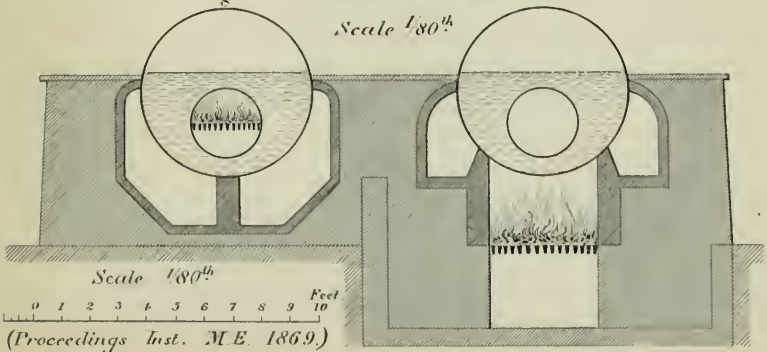


Fig. 4. *Plan.*
*Scale 1/250th*

Fig. 5. *Transverse Section.*
*Scale 1/80th*

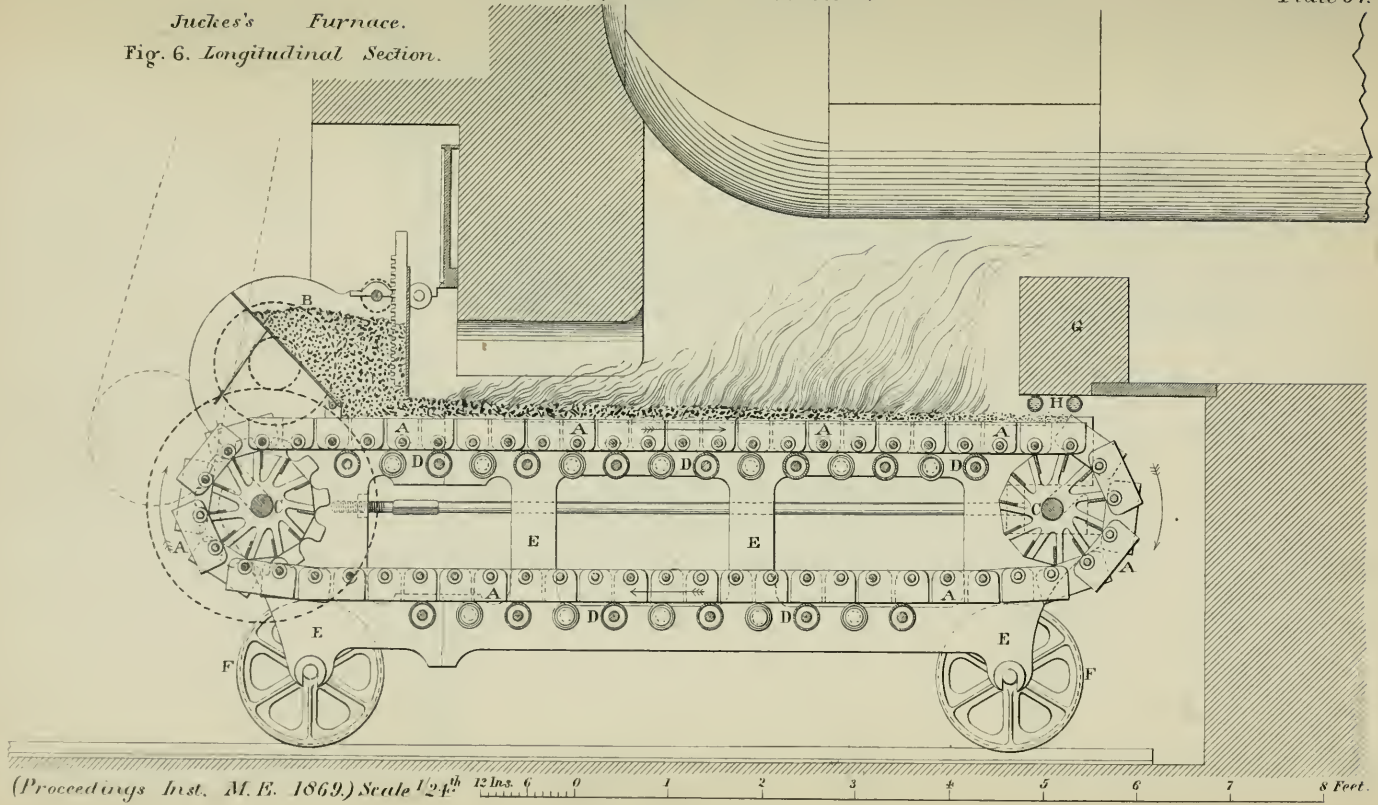


Scale 1/80th
0 1 2 3 4 5 6 7 8 9 10 Feet

(*Proceedings Inst. M.E. 1869.*)

*Juckes's Furnace.*

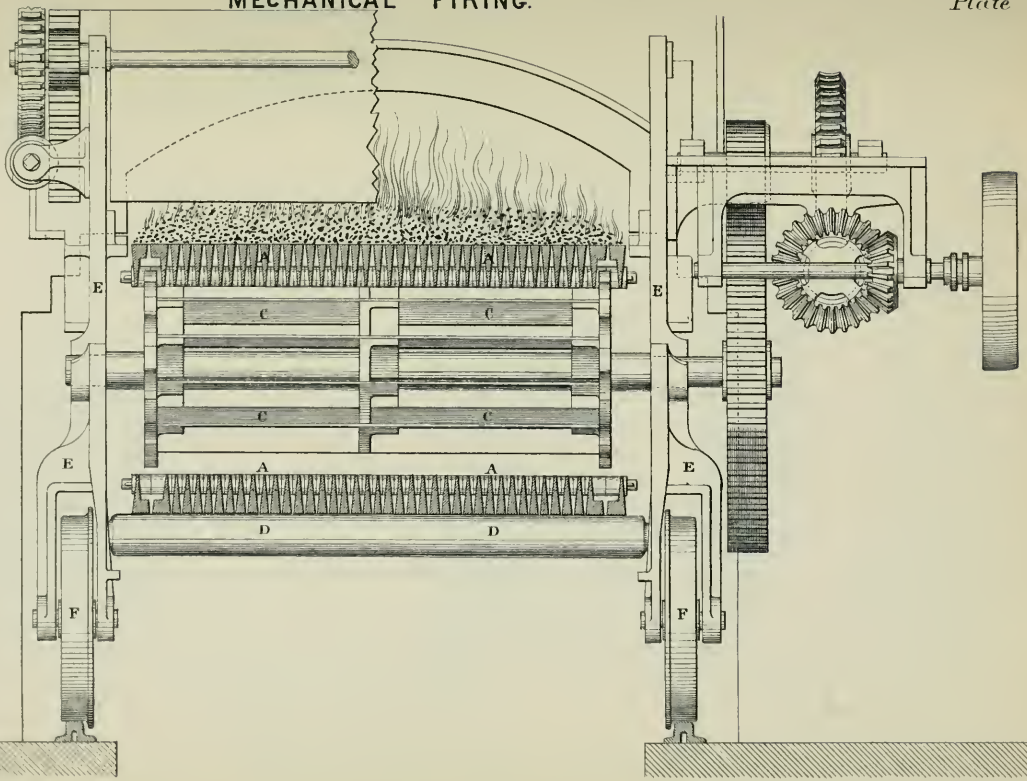
Fig. 6. *Longitudinal Section.*




(*Proceedings Inst. M.E. 1869.*) Scale 1/24th

*Juckes's Furnace.*

Fig. 7. *Front Elevation.*




*(Proceedings Inst. M. E. 1869.)* *Scale 1/16th*

10 5 0 10 20 30 40 50 Inches.

*Juckes's Furnace.*

Fig. 8. *Transverse Section.*

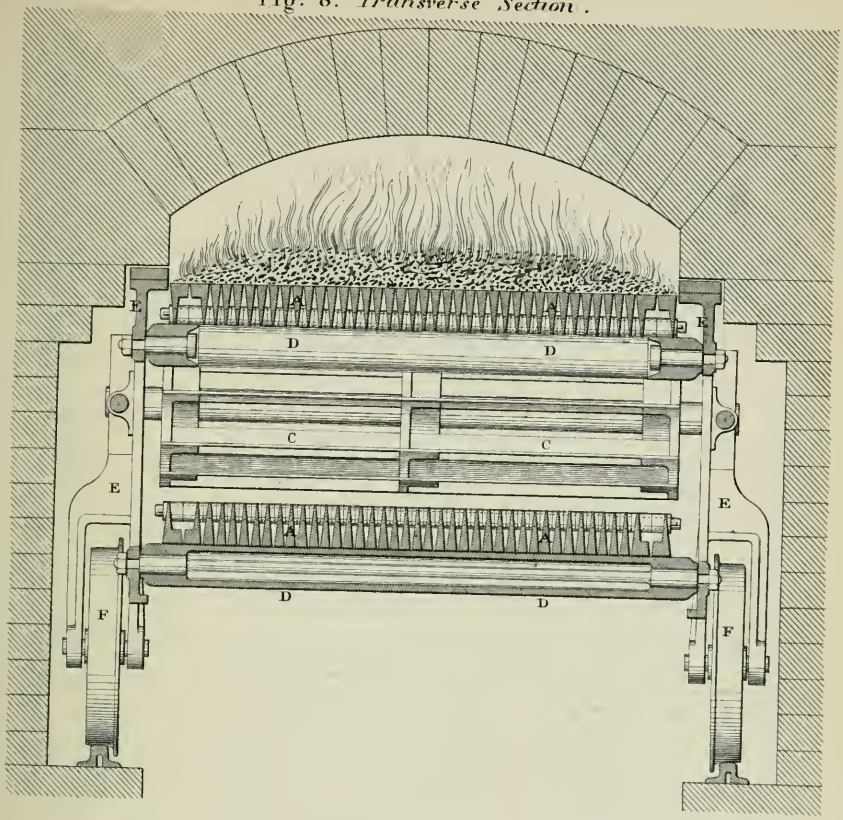
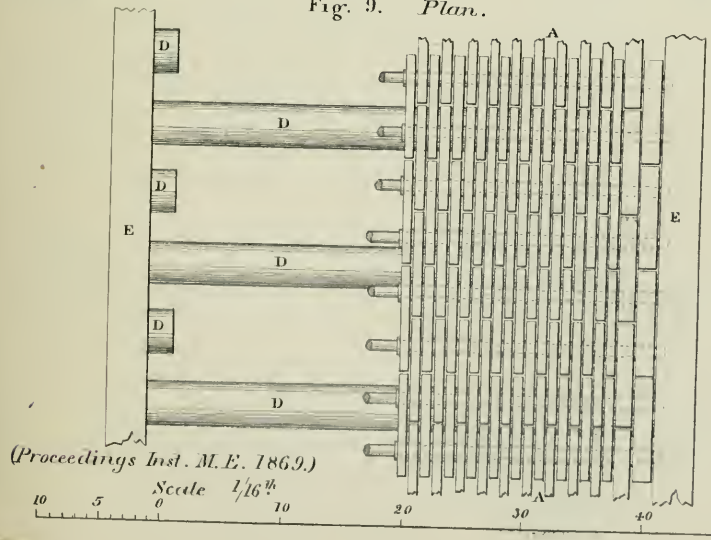



Fig. 9. *Plan.*




*(Proceedings Inst. M.E. 1869.)*

Scale 1/16th

10 5 0 10 20 30 40 50 Inches.

# MECHANICAL FIRING.

*Plate 40.*

*Stanley's Furnace.*

Fig. 10. *Front Elevation.*

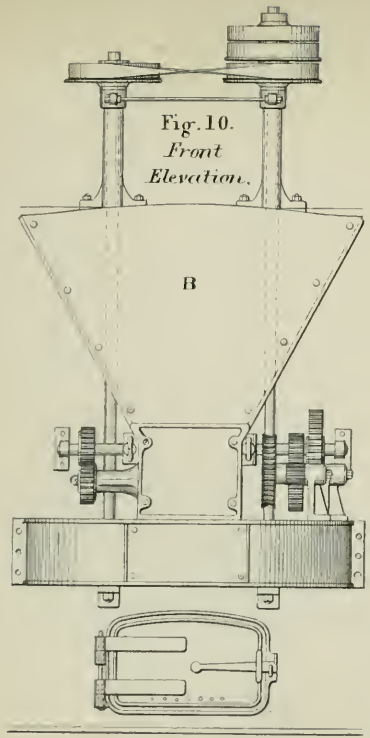
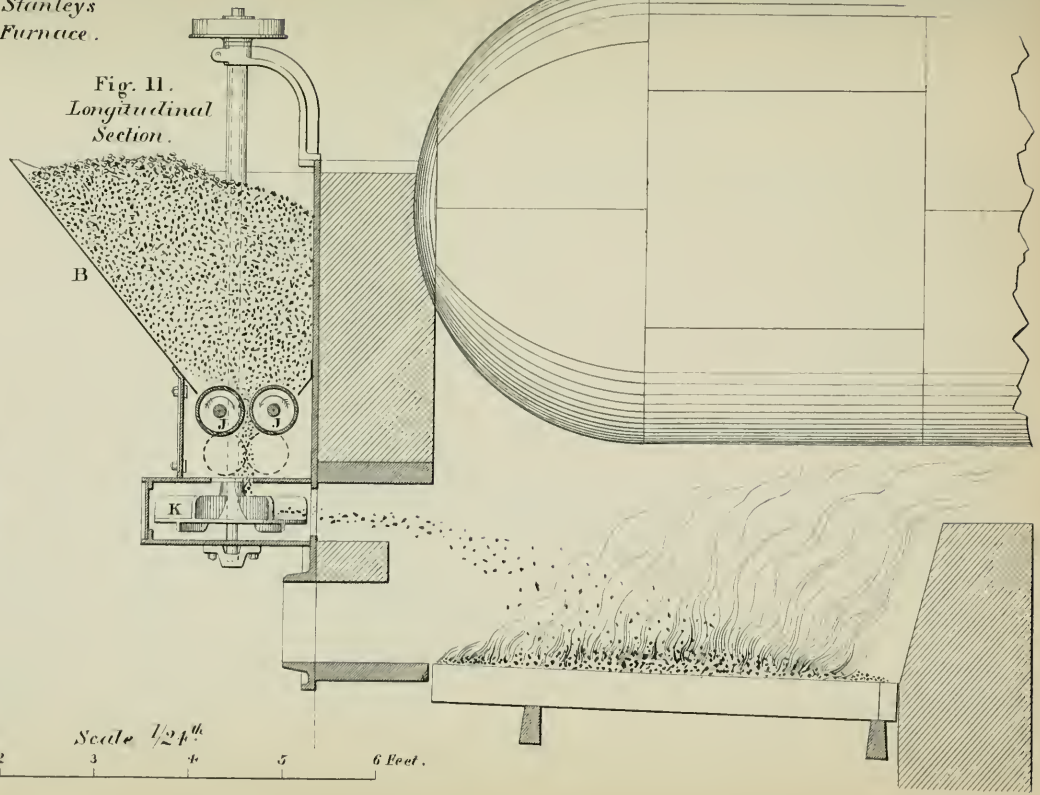



Fig. 11. *Longitudinal Section.*




*(Proceedings Inst. M.E. 1869)* *Scale 1/24th*

Ins. 12 6 0 1 2 3 4 5 6 Feet.

*Stanley's Furnace.*

Fig. 12.
*Vertical Section of Feeding Hopper.*

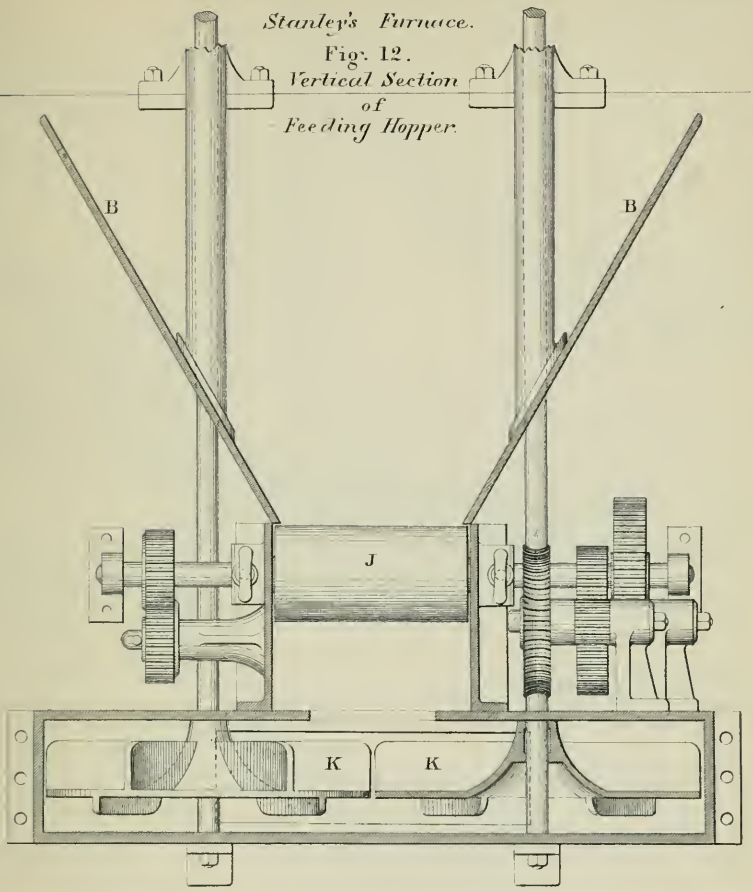
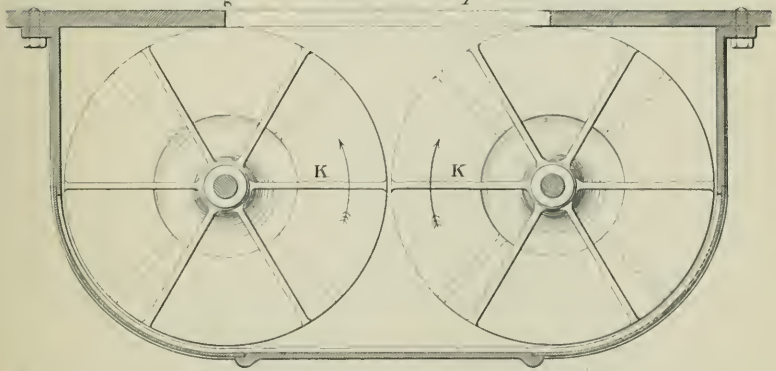



Fig. 13. *Plan of Dispersers.*




*(Proceedings Inst. M.E. 1869)* *Scale 1/12th*

10 5 0 10 20 30 Inches.

*Vicars's Furnace.*

Fig. 14.
*Longitudinal Section.*

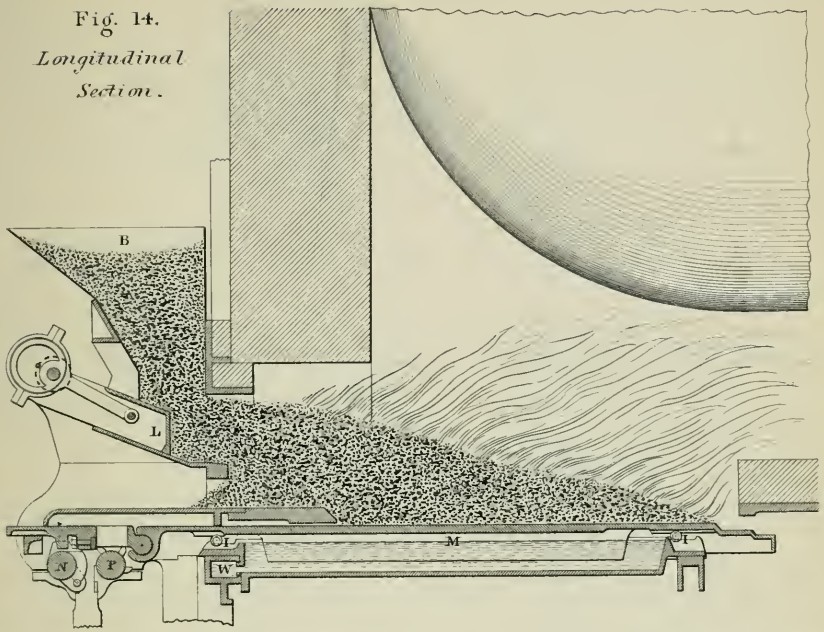
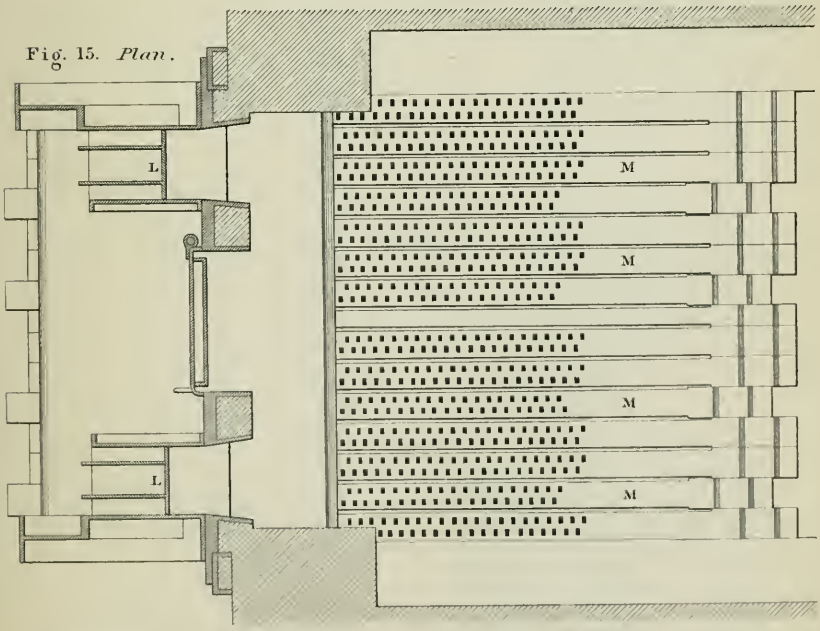



Fig. 15. *Plan.*




*(Proceedings Inst. M. E. 1869.)*

Scale $\frac{1}{24}$th

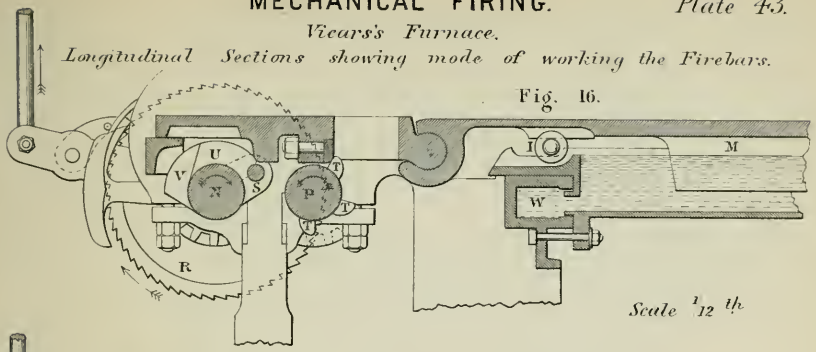
Ins. 12 6 0 1 2 3 4 5 6 Feet.

# MECHANICAL FIRING. *Plate 43.*

*Vicars's Furnace.*

*Longitudinal Sections showing mode of working the Firebars.*

Fig. 16.




*Scale $\frac{1}{12}$ th*

Fig. 17.

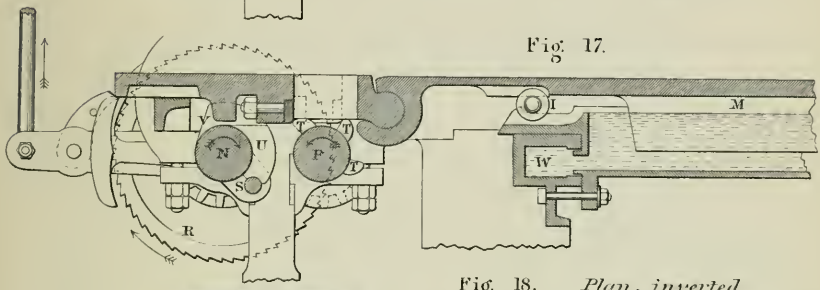
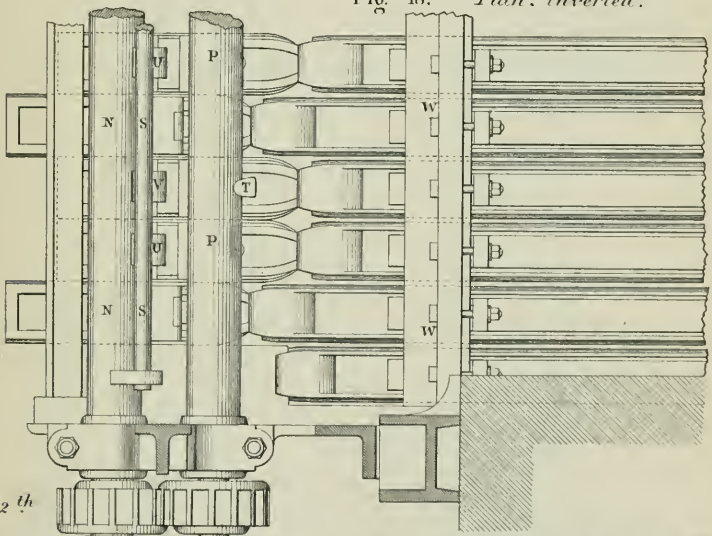



Fig. 18. *Plan, inverted.*




*Scale $\frac{1}{12}$ th*

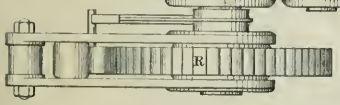
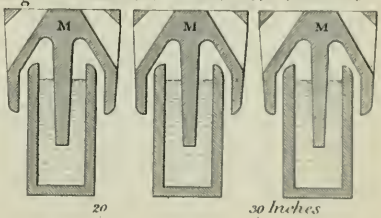



Fig. 19. *Section of Firebars. Scale $\frac{1}{6}$ th*




*(Proceedings Inst. M.E. 1869.)*

*Scale $\frac{1}{12}$ th*

30 20 10 0 5 10 Inches

# VELOCITY OF PROJECTILES.



*Connection of Electric Wires with Bore of Gun.*

Fig. 1. *Longitudinal Section.*

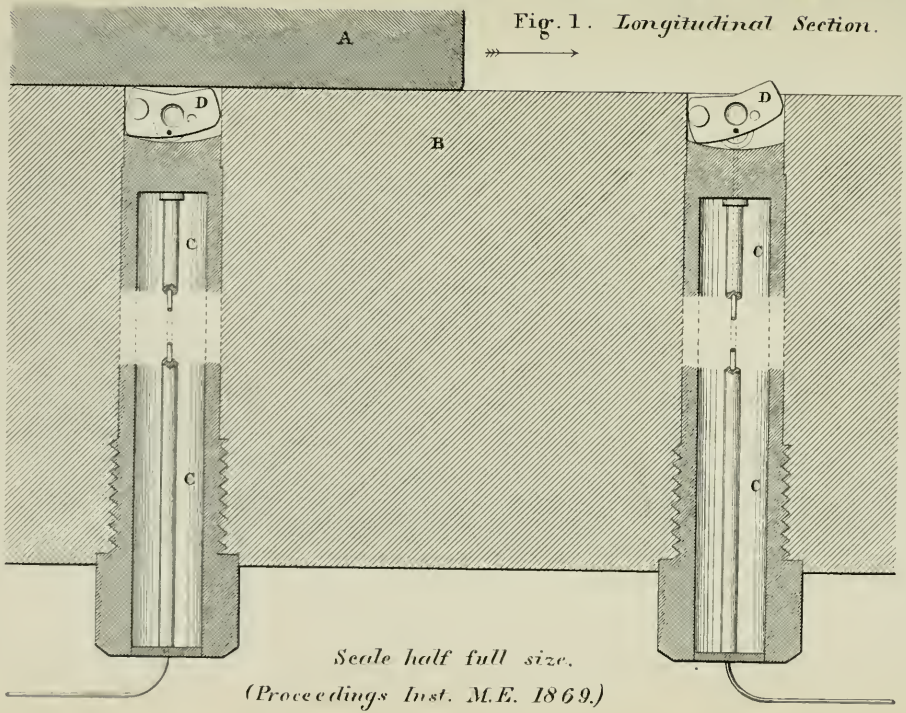
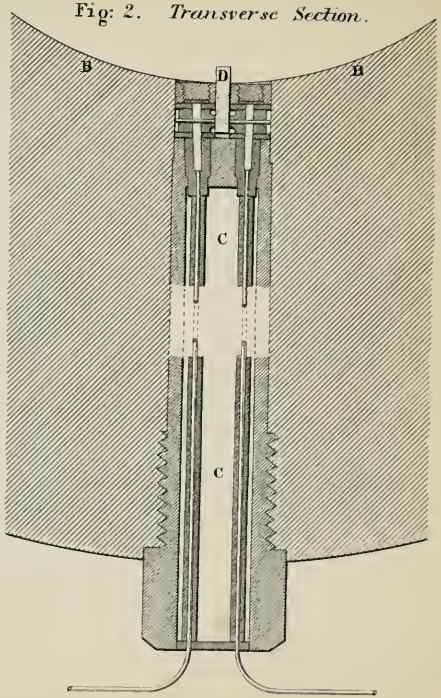



Fig. 2. *Transverse Section.*




*Scale half full size.*

*(Proceedings Inst. M.E. 1869.)*

Fig. 3. *Diagram obtained with Fast-burning Powder.*

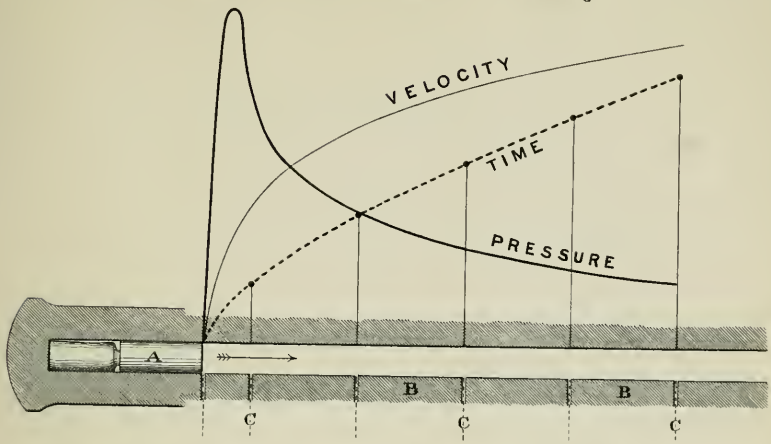
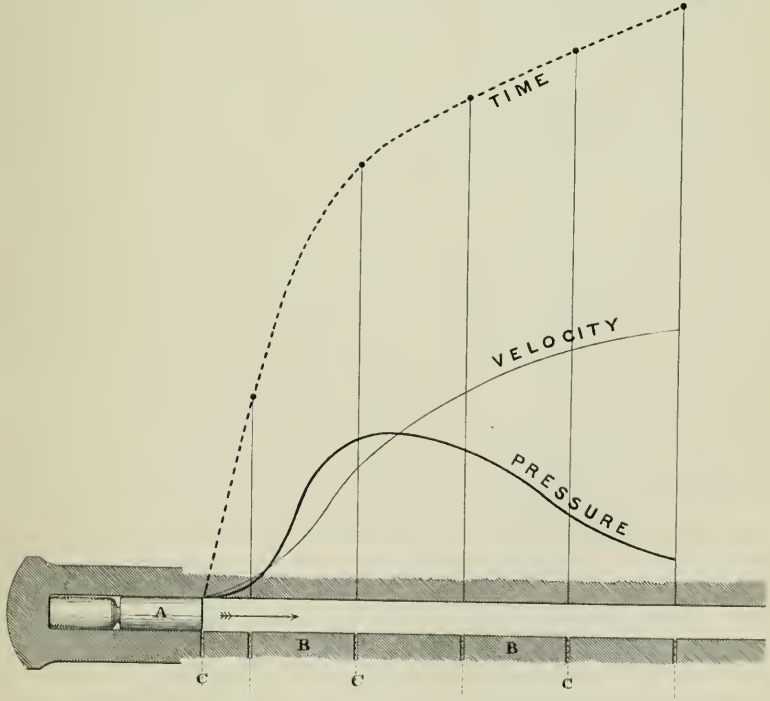



Fig. 4. *Diagram obtained with Slow-burning Powder.*




*(Proceedings Inst. M.E. 1869)*

# PROCEEDINGS.

3 and 4 August, 1869.

The Annual Meeting of the Members was held in the Lecture Theatre of the Literary and Philosophical Society, Newcastle-on-Tyne, on Tuesday, 3rd August, 1869; Sir William G. Armstrong, President, in the Chair.

The President congratulated the Members upon the very satisfactory position of the Institution at the present time, the number of Members having considerably more than doubled during the eleven years which had elapsed since the former Meeting of the Institution in Newcastle; and the high character of the Papers read at the Meetings in respect of mechanical interest and value was very marked. On the occasion of the present Meeting in Newcastle, he was sure the Members would receive a cordial welcome on all sides; and every facility would be afforded them for seeing all that was of interest in connection with engineering.

The Minutes of the last Meeting were read and confirmed.

The President announced that the Ballot Lists had been opened, and the following New Members were duly elected :—

MEMBERS.

| | |
|---|---|
| Thomas Aveling, . . . . | Rochester. |
| Walter Raleigh Browne, . . | Kidderminster. |
| James Campbell, . . . . | Leeds. |
| Hans William Caspersen, . . | Newcastle-on-Tyne. |
| Thomas Checkley, . . . . | Walsall. |
| Robert Calvert Clapham, . . | Newcastle-on-Tyne. |
| Francis North Clerk, . . . | Wolverhampton. |
| John Daglish, . . . . | Seaham. |

| | |
|---|---|
| St. John Vincent Day, | Glasgow. |
| Max Eyth, | Leeds. |
| Henry Faija, | Stoke-upon-Trent. |
| John Fairless, | Newcastle-on-Tyne. |
| Malcolm Gillies, | London. |
| Thomas Minchin Goodeve, | London. |
| Jeremiah Head, | Middlesbrough. |
| Henry Hind, | Nottingham. |
| Thomas Maughan, | Cramlington. |
| George May, | Fence Houses. |
| Frederic William North, | Rowley Regis. |
| Alfred Septimus Palmer, | Newcastle-on-Tyne. |
| William Aubone Potter, | Cramlington. |
| Robert Charles Ransome, | Ipswich. |
| Walter Williams, | Tipton. |

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The following paper was then read:—

# DESCRIPTION OF THE HYDRAULIC SWING BRIDGE FOR THE NORTH EASTERN RAILWAY OVER THE RIVER OUSE NEAR GOOLE.

By SIR WILLIAM G. ARMSTRONG, President.

The formation of the Hull and Doncaster section of the North Eastern Railway necessitated crossing the river Ouse by an opening bridge, so as to admit the passage of the important traffic carried on the river in large sailing vessels. It was also necessary that there should be not more than one pier in the navigable channel, with a clear opening of not less than 100 feet on each side. The requirements of the railway and river traffic necessitated a construction of bridge admitting of being opened and closed very rapidly; and it was also requisite that the power applied should be capable of controlling with great accuracy the momentum of so ponderous a mass. Under these circumstances the bridge described in the present paper was designed by Mr. Harrison, the Engineer of the Railway, with a view to the application of hydraulic pressure as the moving agent.

The instances in which hydraulic power had previously been applied to the opening and closing of movable bridges are very numerous, amounting to upwards of fifty examples. Most of these bridges have been erected for the passage of railway traffic, both on main lines and branches; and they may be divided into three classes.

1st. Swing bridges in which the bridge is lifted from its solid bearings by a central press, previously to being turned round by hydraulic power.

2nd. Swing bridges in which the bridge rests upon a circle of live rollers and is turned by water pressure without being lifted.

3rd. Draw bridges, in which the movable platform is drawn back and pushed forwards again in the line of the roadway by means of hydraulic machinery.

There is also one example of a bridge worked by hydraulic power on the "bascule" plan of the old lifting draw-bridges; this is at Liverpool over one of the dock entrances.

The first hydraulic swing-bridge was erected in 1852 over the river Severn on the Gloucester and Dean Forest Railway; and the first hydraulic draw-bridge was erected in 1853 over the river Tovey on the South Wales Railway near Carmarthen.

All the swing bridges which turn on a centre pier, and span an opening on each side, have been made to turn on live rollers without being lifted, because in bridges of that construction neither extremity can have any steadying support in the act of turning; but in some instances a central press has been applied to relieve the rollers of part of the weight. Where single-leaf swing-bridges are lifted by a central press, the deflection of the overhanging end is taken off by letting the bridge down upon its solid bearings when closed; but in the case of draw-bridges, and swing-bridges not lifted by a central press, hydraulic machinery is applied to lift the overhanging end or ends, so as to take off their deflection after closing. The openings crossed by these several forms of bridges have varied from 30 to 100 feet span. The heaviest bridge to which the central lifting arrangement has been applied is one over the Regent's Canal near the London Docks, in which instance the weight lifted and turned amounts to 450 tons. In bridges with the central press the head of the lifting ram fits into an inverted cup upon the bridge, in order to allow of a slight oscillating movement; and the bridge in swinging turns upon the water in the press by carrying the ram round with it. The pressure of water employed in the central hydraulic press is about 800 lbs. per square inch, and in the largest of these bridges the diameter of the ram turning upon the water is 51 inches.

In most cases the hydraulic bridges are in connection with a system of water pressure applied to cranes and other machines in the vicinity, the pressure being supplied in the usual manner by steam engines pumping into accumulators. But in some few instances where there is not such a supply of power at hand, the pressure is supplied by hand pumps charging the accumulator, and thus storing up the power ready for application whenever required. At the Ouse

Bridge there was no supply of hydraulic power at hand, and in that instance the total power required was too large to be supplied by hand labour. It was further necessary, on account of the position of the swing bridge, either to convey the power to the centre pier by a pipe under the bed of the river, or to produce it upon the pier by placing a steam engine within the pier itself; and the latter plan was the one adopted.

The construction of the Ouse Bridge is shown in Plates 17 to 24. Figs. 1 and 2 are a general elevation and plan of the entire bridge, and Figs. 3 and 4 show an elevation and plan of the swinging portion to a larger scale. Fig. 5 is a vertical transverse section at the centre pier, showing the engine-room and accumulator which are situated within the centre pier; and Fig. 7 is a plan of the centre pier at the level of the engine-room, showing the arrangement of the driving gear with the steam engines and hydraulic engines. Fig. 8 is an enlarged section of one half of the engine-room, and Fig. 9 a sectional plan of the accumulator. Figs. 11 and 12 are a plan and elevation of the hydraulic engines for turning the bridge; and Figs. 13 to 16 show the gear at the two extremities of the bridge for working the adjusting supports and the locking bolts.

The total length of the bridge, fixed and movable, is 830 feet. The fixed portions consist of five spans of 116 feet each from centre to centre of piers, Figs. 1 and 2, Plate 17. The bridge being for a double line of railway, each span is composed of three wrought-iron plate girders, the centre girder having a larger section to adapt it for its greater load; these girders have single webs and are 9 feet deep in the centre. The total width of the bridge from outside to outside is 31 feet. Each of the piers for the fixed spans consists of three cast-iron cylinders of 7 feet diameter and about 90 feet length. The depth from the underside of the bridge to the bed of the channel in the deepest part is about 61 feet. The headway beneath the bridge is 14 ft. 6 ins. from high water datum and 30 ft. 6 ins. from low water.

The swinging portion of the bridge, Figs. 3 and 4, Plate 18, consists of three main wrought-iron girders, 250 feet long and 16 ft.

6 ins. deep at the centre, diminishing to 4 feet deep at the ends. The centre girder is of larger sectional area than the side girders, and instead of being a single web is a box-girder 2 ft. 6 ins. in width, Fig. 8, with web plates 7-16ths to 5-16ths inch in thickness, and the top and bottom booms contain together about 132 square inches section. The roadway is carried upon transverse wrought-iron girders resting upon the bottom flanges of the main girders, Figs. 8 and 14. In the centre of the bridge the main girders are stayed by three transverse wrought-iron frames securely fixing them together; and over the top of these frames a floor is laid, from which the bridgeman controls the movements of the bridge.

An annular box-girder A A, 32 feet mean diameter, is situated below the centre of the bridge and forms the cap of the centre pier, Figs. 5 and 8, Plates 19 and 21; this girder is 3 ft. 2 ins. in depth and 3 feet in width, and rests upon the top of six cast-iron columns, each 7 feet diameter, which are arranged in a circle and form the centre pier of the bridge. Each of these columns has a total length of 90 feet, being sunk about 29 feet deep in the bed of the river. A centre column B B, 7 feet diameter, is securely braced to the six other columns by a set of cast-iron stays, which support the floor of the engine-room. This centre column contains the accumulator C, Fig. 5, and forms the centre pivot for the rotation of the bridge.

The weight of the swing bridge is 670 tons. There is no central lifting press, and the entire weight rests upon a circle of conical live rollers E E, Figs. 5 and 8. These are 26 in number, as shown in the plan, Fig. 6, Plate 20; they are each 3 feet diameter with 14 inches width of tread, as shown in Fig. 10, and are made of cast iron hooped with steel. They run between the two circular roller paths D D, 32 feet diameter and 15 inches broad, which are made of cast iron faced with steel; the axles of the rollers are horizontal, and the two roller paths are turned to the same bevil.

The turning motion is communicated to the bridge by means of a circular cast-iron rack G, Fig. 8, $12\frac{1}{2}$ inches wide on the face and $6\frac{1}{2}$ inches pitch, which is shrouded to the pitch line and is bolted to the outer circumference of the upper roller path. The rack gears with a vertical bevil wheel H, which is carried by a steel centre pin J

supported in the lower roller path; and this wheel is driven by a pinion connected by intermediate gearing with the hydraulic engine. There are two of these engines, duplicates of one another, which are situated at K K in the engine room, Figs. 7 and 8; and either of them is sufficient for turning the bridge, the force required for this purpose being equal to about 10 tons applied at the radius of the roller path. Each hydraulic engine is a three-cylinder oscillating engine, as shown in Figs. 11 and 12, Plate 23, with simple rams of $4\frac{1}{4}$ inches diameter and 18 inches stroke. These engines work at 40 revolutions per minute with a pressure of water of 700 lbs. per inch, and are estimated at 40 horse power each. The steam engines for supplying the water pressure are also in duplicate, situated at L L, Fig. 7, and are double-cylinder engines driving three-throw pumps of $2\frac{3}{4}$ inches diameter and 5 inches stroke, which deliver into the accumulator. The steam cylinders are 8 inches diameter and 10 inches stroke, each engine being 12 horse power.

The accumulator C, Fig. 5, shown also in the sectional plan Fig. 9, Plate 22, has a ram $16\frac{1}{2}$ inches diameter with a stroke of 17 feet; it is loaded with a weight of 67 tons, composed of cast-iron segments suspended from a crosshead and working down inside the cylindrical casing formed by the centre cylinder of the pier. A pair of cross beams M M are fixed to limit the rise of the weight.

For the purpose of obtaining a perfectly solid roadway when the bridge is in position for the passage of trains, and also for securing the perfect continuity of the line of rails, the following arrangement is adopted, shown in Figs. 13 to 16, Plate 24. Each extremity of the bridge is lifted slightly by a horizontal hydraulic press N, Figs. 13 and 14, acting upon the levers P P which form a toggle joint; the press has two rams acting in opposite directions upon two toggle-joint levers, which are connected by a horizontal bar Q, and this bar is confined to a vertical movement by a stud sliding in a vertical guide, so as to ensure an exactly parallel action of the two toggle-joint levers, in order thereby to lift the bridge end exactly parallel. While the end of the bridge is thus held lifted, the three resting blocks R R, one under each girder, are pushed home by means

of three separate hydraulic cylinders S S, Figs. 15 and 16; the bridge is then let down upon these resting blocks by the withdrawal of the toggle-joint levers P P, and the bridge ends are then perfectly solid for trains to pass over. The hydraulic cylinders N and S for working this fixing gear at the two ends of the bridge are controlled by valves placed upon the centre platform in reach of the bridgeman, the pipes from the valves to the cylinders passing along the side of the roadway of the bridge.

For the purpose of enabling the bridgeman to stop the turning movement of the bridge at the right place, an indicator is provided consisting of a dial with two pointers which are actuated by the motion of the bridge. One of these pointers makes 2 revolutions and the other 42 revolutions for one complete rotation of the bridge; they are similar to the hour and minute hands of a watch, the slower pointer being analogous to the hour hand and the quicker one to the minute hand. The bridge has no stop to its turning movement, and would swing clear past its right position if the turning power were continued; but the bridgeman being guided by the indicator knows when to stop and reverse the hydraulic engines for the purpose of stopping the bridge at its right place. When this is done, a strong locking bolt T, Figs. 13 to 15, 3 inches thick, pressed outwards by a spiral spring, is shot out at each end of the bridge into a corresponding slot in the fixed girder, so as to lock the bridge; and when the bridge is required to be opened these two bolts are withdrawn by a wire cord U, Fig. 15, leading to the platform on which the bridgeman is stationed. In consequence of the line of the bridge lying in a north and south direction, the heat of the sun acting alternately on the opposite sides of the bridge produces a slight lateral warping; and in order to bring the ends back into the straight line after swinging the bridge, so as to enable the two locking bolts to enter their slots, the feet of the toggle-joint lifting levers P P are bevilled off at 55° on their inner faces, as shown at I I in Fig. 14, Plate 24, and bear against corresponding bevils V V on the bedplates. By this means the ends of the bridge when warped are forced back into the correct centre line, in which they are then held secure by the locking bolts.

As the accumulator is stationary in the centre pier, while the fixing gear at the ends of the bridge travels with the bridge in swinging, the communication of water power is effected by a central copper pipe W, Fig. 8, Plate 21, passing up in the axis of the bridge through the middle of the centre girder, and having a swivel joint at the lower end. Also as the bridgeman's hand-gear rotates with the bridge while the hydraulic turning engines are stationary, the communication for working the valves is made by a central copper rod X, Fig. 8, passing down through the centre of the pressure-pipe W in the axis of the bridge. The hydraulic engines are reversed in either direction by the action of a small hydraulic cylinder, which is governed by the movement of a three-port valve actuated by the rod X from the bridgeman's platform.

The time required for opening or closing the bridge, including the locking of the ends, is only 50 seconds, the average speed of motion of the bridge ends being 4 feet per second. For the purpose of ensuring safety in the working of the railway line over the bridge, a system of self-acting signals is arranged, which is actuated by the fixing gear at the two ends of the bridge; and a signal of all right is shown by a single semaphore and lamp at each end of the fixed part of the bridge; but this cannot be shown until each one of the locking bolts and resting blocks is secure in its proper place.

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Mr. R. Hodgson, as Resident Engineer on the Railway, said he had great pleasure in bearing testimony to the admirable manner in which the entire work of the swing bridge now described had been executed; nothing could be more satisfactory than the workmanship in every respect, and although the moving mass was of such remarkable size and weight, the movement in turning was so smooth, that not the slightest motion was felt when standing upon the bridge while turning, and with the eyes shut it was impossible to tell that the bridge was moving. All portions of the work were most efficient

in every respect, and the report of the Government Railway Inspector stated that the bridge was by far the most perfect and most complete structure of the kind that had ever been erected.

In regard to the construction of the piers supporting the fixed and the movable portions of the bridge, these were constructed of cast-iron cylinders of 7 feet diameter up to low water level, tapering to 5 ft. 6 ins. diameter at high water. A timber staging with guides was erected at each pier for sinking the cylinders in their proper position, and they were sunk through the silt of the river bed by a dead weight placed on each; and on arriving at the water bearing strata the pneumatic process was adopted, with a pressure of air reaching to 36 lbs. per square inch and equivalent to 83 feet head of water. The sinking was carried down by this means till the cylinders rested upon the new red sandstone rock at a depth of 92 feet below the level of the railway, and they were filled up with Portland cement concrete to a height of about 20 feet from the bottom, while the pneumatic pressure was still kept upon them; after which it was taken off, and they were built up solid with brickwork in cement, finishing with a course of granite at the top, upon which the bridge girders rested. After filling the cylinders in solid with the concrete and brickwork, they were tested by being subjected to the pressure of a dead weight; the centre pier, composed of six cylinders, was loaded with 500 tons, and the side piers, composed of three cylinders, were loaded with 250 tons each; and in no case were any of the piers found to go down under this testing load more than $\frac{1}{2}$ inch. On the occasion of the testing of the bridge by the Government Inspector, four of the heaviest locomotives were placed on each line of rails, and the deflection did not amount in any of the girders to more than 0·4 inch, which was an unusually small deflection for the span of 116 feet.

Mr. J. Ramsbottom observed that the great work which had been accomplished in spanning so large an opening by the swing bridge now described was one of particular interest to all connected with railways; and the opening and shutting of so large a bridge in so very short a space of time could only be efficiently done by the employment of hydraulic machinery, storing up the requisite power

by means of an accumulator charged during the time that the bridge was standing. He enquired whether steel had been used in the construction of the girders, for the purpose of reducing the weight of the moving mass in the swinging portion of the bridge.

The PRESIDENT replied that the girders of the bridge were made of wrought iron, and the only parts where steel had been used were the tyres of the rollers on which the bridge turned, and the facing of the roller paths. There was such entire control over the movements of the bridge by the ample supply of hydraulic power at command, that he did not think the reduction of weight consequent upon the use of steel in the construction of the girders would materially have facilitated the working of the bridge. The magnitude of the parts would certainly have been somewhat reduced by the employment of steel, but the question was mainly one of cost of construction in the first instance.

Mr. H. CHAPMAN enquired what was the amount of steam power employed in charging the accumulator for working the bridge.

The PRESIDENT replied that one steam engine of 12 horse power was employed to charge the accumulator, the throttle-valve in the steam pipe being regulated by the rise and fall of the accumulator ram, so that the engine started pumping whenever the accumulator was lowered, and kept the accumulator always charged full, ready for action. A duplicate steam engine was provided, to be ready for use at any time in the event of stoppage of the other engine.

Mr. L. OLRICK mentioned that, for the purpose of confining within a small space the steam power required for charging the accumulator, the pair of boilers used were of the construction known as "Field" boilers, having vertical double water-tubes, and each boiler was only $4\frac{1}{2}$ feet diameter and $6\frac{1}{2}$ feet high, so that they took up very little room in the limited space available within the central pier of the bridge; they had also the advantage of raising steam much more quickly than other constructions of boilers. In the present instance the situation of the boilers did not allow of the usual vertical uptake passing out at the top, and the flue was consequently carried down at the side and continued horizontally to a chimney at the end of the stage adjoining the pier.

Mr. E. A. Cowper observed that the circular girder forming the upper roller path on the central pier did not appear to be made of such depth and stiffness as the circular girder forming the lower roller path; and he enquired whether, during the time that the bridge was standing still with a load on it, this girder was found to be stiff enough to distribute the weight uniformly upon all the rollers round the circle, and prevent the load coming heavier upon those rollers that were immediately underneath the central girder of the bridge.

Mr. Westmacott replied that he had not observed whether there was any deflection in the upper circular girder from the effect of a load on the bridge, and he believed it had sufficient stiffness for distributing the weight equally upon all the rollers. There had not been the means of actually ascertaining the uniformity of weight upon the rollers when the bridge was standing with a load upon it; but in swinging round it was found that all the rollers turned equally, and it was therefore inferred that they all bore a share of the load.

Mr. T. L. Gooch enquired whether any provision had been made to ensure the working of the hydraulic apparatus in frosty weather.

Mr. Westmacott replied that gas jets were provided in the central pier and in the chambers containing the hydraulic cylinders at the ends of the bridge, which would be kept burning in frosty weather to prevent the water from freezing; and the pipes leading to the machinery at the ends of the bridge were enveloped with cinders enclosed in wooden boxes. The gas was supplied from Goole to the south end of the bridge, and was delivered into a storage reservoir composed of elastic bags contained in the bridgeman's house, from which the supply of gas to the burners was maintained during the time the bridge was open. The two disconnected ends of the gas pipe were each closed during the swinging of the bridge by self-acting valves, which opened inwards into the pipe and were closed by a spiral spring, preventing the escape of the gas; the centre spindle of each valve projected beyond the extremity of the pipe, and the pipe on the swinging portion was made with a telescopic sliding end, which whenever a supply of gas

was desired to be taken in was pushed outwards by means of a rod and handle worked from the centre of the bridge, so as to make a tight joint with the end of the stationary pipe and at the same time open the valves.

The PRESIDENT remarked that in the climate of this country hydraulic machinery was in all cases found to be preserved from frost when sunk in the ground only as much as 2 feet depth and covered over with planking. Where the hydraulic cylinders were fixed in chambers, as in the bridge now described, a very small jet of gas kept constantly burning was quite sufficient to exclude the frost. Another expedient, which could be resorted to when no gas could be obtained, had been adopted in the case of the drawbridge on the South Wales Railway over the river Tovey near Carmarthen, by mixing the water of the hydraulic apparatus with common cheap methylated spirit, which entirely prevented freezing; and the same water was used over and over again, so that there was no waste of the spirit.

Mr. I. LOWTHIAN BELL said he had great pleasure in mentioning that the statements which had been made by the resident engineer of the North Eastern Railway, as to the admirable execution of the entire work of the bridge, were fully corroborated by the great satisfaction expressed by the directors at the complete success with which the whole of this remarkable engineering work had been performed, and the great amount of skill displayed in its accomplishment. Even when regarded only in its stationary condition, the magnitude of the bridge was sufficient to stamp it as a structure of importance in railway engineering; and much more was this the case when it was contemplated as a swing bridge, and when the vast weight of so large a moving mass was taken into consideration, together with the perfect control exercised over all its movements by means of the hydraulic apparatus by which it was worked.

With regard to the facilities afforded by the hydraulic system for lifting heavy loads, he had now had hydraulic apparatus at work for more than three years at the Clarence Iron Works in the county of Durham, constructed by Sir William Armstrong's firm, and employed for lifting materials for the blast furnaces at the rate of

2000 tons per day; and after once being started fairly to work, there had never been a single stoppage of the machinery from any defect in the apparatus either in frosty weather or under any other circumstances.

He moved a vote of thanks to the President for his very interesting paper, which was passed.

The PRESIDENT said it was highly gratifying to find that the construction of this swing bridge had met with the entire satisfaction of the North Eastern Railway Co., and also that it had afforded the subject for a paper of interest to the Members of the Institution, who would have an opportunity, through the kindness of the North Eastern Railway, of inspecting the bridge and witnessing its performance in working.

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The following paper was then read:—

# ON THE VARIOUS SYSTEMS OF VENTILATION OF MINES.

By Mr. WILLIAM COCHRANE, of Newcastle.

In contemplating the great advances which have been made in the development of mining enterprise, and taking into consideration also the future requirements of the coalfields, it must be admitted that adequate Ventilation is not inferior in importance to any other of the practical questions connected with mining.

In the earliest mining operations no ventilation was provided for beyond that arising from the natural conditions of the mines; and so long as mines were only worked to a very limited extent by levels or adits or by shafts of very small depth, the natural ventilation was found to answer all requirements. It had the disadvantage however that the determination of the current of air was dependent on the average temperature of the mine being either above or below that of the external atmosphere, a condition continually varying throughout the year; and there was therefore never any certainty as to the direction of current or the quantity of air which could be obtained for ventilating the mine. Natural ventilation is still used in mines of limited extent, where also the nature of the mine offers only a very small resistance to the current of air circulating. Under these conditions, as in the Staffordshire "Thick coal" mines, the determination of the air current into a particular course is often ensured by placing a fire lamp in the upcast shaft; but this contrivance can only produce a very small effect, and is therefore of limited application. On a larger scale however the same principle has been the one most generally adopted for mine ventilation in this country, by means of the Ventilating Furnace.

The useful effect of the furnace, and the conditions necessary for its most perfect action, are readily deduced from a consideration

of the effects of the expansion of air by heat. When the pressure remains the same, the volume of air is expanded by each degree of rise in temperature to the extent of 1-459th part of its corresponding volume at the temperature of zero Fahrenheit; so that the length of a column of air of the same sectional area in the heated upcast shaft is increased in the proportion of (459 + temperature of upcast shaft) to (459 + temperature of downcast shaft). The difference between the weights of these two columns of air having the same total height forms the ventilating pressure; and as the velocity of a current of air is proportionate to the square root of the pressure producing it, the velocity of the current in a mine, and consequently the volume of air circulating through passages of given area and length in the mine, is proportionate to the square root of the difference between the temperatures of the upcast and downcast shafts, when the depth of the upcast shaft remains constant; or it is proportionate to the square root of this depth when the difference of temperature between the upcast and downcast shafts remains constant. From this consideration it will be seen how soon a practical limit is reached in increasing the ventilation of a mine, either by increased temperature, or by any increased height of shaft such as is sometimes obtained by continuing it above the ground level as a chimney; and the small efficiency of a fire lamp, as before alluded to, or of a furnace placed at the surface, is also apparent. A limit to the useful effect produced by the heated upcast shaft has moreover been proved to exist at a temperature of about 570° Fahr.; because above that temperature the diminution in the total weight of the air in the shaft, consequent upon its expansion in volume, counteracts the gain resulting from the increased velocity of current caused by the further expansion of the air.

Some of the best examples of furnace ventilation are to be found in the Northumberland and Durham coalfield; and one illustration will suffice to show that under favourable conditions this system affords a ventilating power of great importance. At the Seaham Colliery near Sunderland, 221,177 cubic feet of air per minute were measured as the total of the intake currents on 1st July last, and

294,171 cubic feet in the upcast shaft at an average temperature of 225°. The resistances to this current, as indicated by the water gauge, were represented by 4·73 inches of water at the top of the downcast shaft and 3·65 inches at the bottom. The downcast shaft is 508 yards deep and 14 feet diameter, and the upcast shaft the same diameter and 512 yards deep. There are two ventilating furnaces, each 9½ feet by 7½ feet, and each consuming 9·15 tons of coal in twelve hours; and four boiler fires in the seam, each 5 feet by 6 feet, consuming together 18·97 tons of coal in twelve hours, and working into the upcast shaft. The temperature in the upcast shaft is 290° immediately above the furnace drift, 235° at half the depth, and 215° at the surface, the temperature of the return air from the workings being 74° near the furnaces. All the furnaces in this case are built with air passages on each side, a precaution necessary to ensure safety against any transmission of the heat to the adjoining strata, the neglect of which has often been the cause of serious fires in coal seams.

The duty therefore of these ventilating furnaces at Seaham Colliery, assuming 25 per cent. of the coal burnt under the boilers to be utilised for the purpose of ventilation, is represented by 4301 lbs. of coal consumed per hour for 127 horse power in the intake air current, taking the water gauge at the bottom of the downcast shaft. This is equal to a consumption of 34 lbs. of coal per hour per horse power in the air measured as above; but as an assumption respecting the total consumption of coal is here made which is liable to error, it will be better to consider the results obtained where ventilating furnaces are used alone, instead of in conjunction with steam boiler furnaces. Observations of this description have been made at different collieries in the northern coalfield, under various conditions as to depth of shafts, extent of workings, and thickness of the seams of coal: the vacuum being indicated by a water gauge placed in the mine, and therefore representing only the work done in overcoming the friction due to the mine, exclusive of the friction in the two shafts. The particulars of these observations are given in the following table, and the general result is that the consumption of coal with the ventilating furnaces

*Table showing Duty of Ventilating Furnace at different collieries in the Northumberland and Durham coalfield.*

| Name of Colliery. | Downcast Shaft. | | Upcast Shaft. | | Area of Furnace Grate. | Temperature of Air. | | | | | | Volume of Air circulated per minute. | Water Gauge in the mine. | Coal consumed in 12 hours. | Consumption of Coal per hour per H.P. in the Air. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Diameter. | Depth. | Diameter. | Depth. | | Top of Downcast. | Bottom of Downcast. | Return Air near Furnace. | Bottom of Upcast. | Half-way in Upcast. | Top of Upcast. | | | | |
| | Feet. | Yards. | Feet. | Yards. | Sq. Ft. | Fahr. | Fahr. | Fahr. | Fahr. | Fahr. | Fahr. | Cub. Ft. | Inches. | Cwts. | Lbs. |
| Rugeley | 12 | 160 | 12 | 160 | 64 | ... | ... | 61 | 141 | 117 | 110 | 103,325 | 0·62 | 40 | 37·0 |
| Page Bank | 12 | 90 | 9 | 100 | 72 | ... | ... | ... | ... | ... | ... | 39,997 | 0·90 | 25 | 41·1 |
| North Seaton | 15½ | 250 | 9 | 266 | 72 | 68 | 70 | 65 | 225 | 206 | 186 | 99,750 | 1·10 | 91 | 49·2 |
| Ryhope | 15 | 508 | 10½ | 460 | 160 | 62 | ... | 76 | 170 | ... | 134 | 126,366 | 1·00 | 120 | 56·3 |
| Trimdon | 12½ | 208 | 8 | 160 | 54 | ... | ... | ... | ... | ... | ... | 40,000 | 0·50 | 30 | 89·0 |
| Pelton | 7, 7, 10½ * | 108 | 7½ | 106 | 48 | ... | ... | ... | ... | 207 | ... | 36,350 | 1·10 | 68½ | 101·6 |

* Downcast shafts, two of 7 feet and one of 10½ feet diameter.

varies from 37 to 101 lbs. of coal per hour per horse power in the air circulated in the mine, these results being arrived at with currents of air ranging from 36,000 to 126,000 cubic feet per minute.

With regard to the best construction of ventilating furnace and the most economical mode of feeding it with air, the general result of the experiments that have been made seems to favour the adoption of a large open grate surface, the maintenance of a thin fire, and the supply of fresh air direct from the downcast shaft in case there is any risk of the return air bringing with it an explosive mixture: otherwise the whole of the return air can be passed over and through the furnace. A grate closed with firedoors is sometimes used, and a more rapid and perfect combustion of the fuel is thereby attained, but with inferior results per lb. of coal in the same mine as compared with the open grate. Experiments were made upon this subject by the late Mr. Nicholas Wood at the Eppleton and Elemore Collieries in the county of Durham, the particulars of which are given in the following table. At Eppleton it was found that by the change from an open to a closed furnace the volume of air circulating in the mine could be increased by means of the increased consumption of coal per hour upon the same surface of grate; but this resulted in a loss of 22 per cent. in the duty obtained from the fuel. At Elemore the result of a similar change was a loss in duty of 40 per cent. The increased wear and tear in the furnace brickwork, attending the use of a closed grate, render it unadvisable for adoption except in special cases.

*Experiments showing Loss of Duty with* Closed *Ventilating Furnace instead of* Open *Furnace.*

| | Area of Furnace Grate. | Volume of Air circulated per minute. | Water Gauge in the mine. | Coal consumed per hour. | Consumption of Coal per hour per H.P. in Air. | Loss of Duty with Closed Furnace. |
|---|---|---|---|---|---|---|
| EPPLETON. | Sq. Ft. | Cub. Ft. | Inches. | Cwts. | Lbs. | Per cent. |
| Open furnace | 156 | 61,360 | 1·05 | $5\frac{1}{4}$ | 58·0 | ... |
| Closed ,, | 156 | 71,600 | 1·30 | $9\frac{3}{4}$ | 74·6 | 22 |
| ELEMORE. | | | | | | |
| Open furnace | 156 | 46,596 | 1·00 | $3\frac{1}{8}$ | 47·7 | ... |
| Closed ,, | 156 | 47,775 | 1·07 | $5\frac{3}{4}$ | 80·1 | 40 |

Depth of shaft is the most important consideration for the efficient application of a furnace, but there are other conditions which it is necessary to secure: namely that the shaft be dry, and that it be lined with a good heat-retaining material. A fair estimate of the economic value of ventilating furnaces, in the average conditions under which they are worked, is considered to be that only 5 per cent. of the heat due to the combustion of the coal is utilised. Besides this small amount of useful effect however in the employment of the furnace, there are also many objections that cannot be overcome, which form a constant source of cost attendant upon furnace ventilation. These are—the necessity of cleaning the furnace flues, and the consequent suspension of the active ventilation of the mine;—the inconvenience and in some cases the impossibility of using the upcast shaft, highly heated and often full of smoke, for any other purpose than as a ventilating shaft;—the serious damage occasioned by the products of combustion, especially when the shaft is damp, to the cast-iron tubbing in the shaft, to the timber and pumps, and to the wire ropes where winding is carried on in the upcast shaft;—and also the cost of labour in firing. If the conditions are unfavourable for the use of a furnace, as in the case of shallow shafts and heavy resistances to be overcome, the furnace is then quite unable to compete in economical effect with a good mechanical ventilator. The limit of the furnace as a ventilating power is soon reached when the resistances offered by a mine are heavy; and this objection naturally led to the adoption of other means for meeting the conditions under which the furnace would fail to afford a sufficient ventilation. Machines for blowing fresh air into the mine or exhausting the foul air from it were adopted in the very earliest periods of mining, especially on the continent, where the conditions of the seams are such as to require more efficient ventilation than was supplied by the furnace; hence it is that mechanical ventilators are very numerous abroad, while in this country until very recently they were quite exceptional.

The minimum depth at which a furnace would be equal to a ventilating machine in point of economy of fuel has been estimated by Mr. J. J. Atkinson, Government Inspector for the Durham

coalfield, on the assumption that the sources of loss are of the same extent in each case: that is, that the loss of fuel in a furnace from the cooling in the upcast shaft is equivalent to the power expended in overcoming the useless resistances in a ventilating machine. On this assumption, and assuming also that the ventilating machine utilises 60 per cent. of the engine power, and that it requires a consumption of 8 lbs. of coal per hour per indicated horse power of the engine, it is calculated that the minimum depth at which the economy by the two plans is equal is 960 yards with an average upcast temperature of 100° Fahr., 1040 yards with 150°, and 1130 yards with 200°. With a higher consumption of coal by the mechanical ventilator the results of the calculation are as given in the following table:—

*Table showing Minimum Depth for equal economy of ventilating Furnace and Mechanical ventilation.*

| Coal consumed by engine. Lbs. per hour per indicated H.P. | Average Temperature in upcast shaft. | Minimum Depth for equal economy of ventilating Furnace and Mechanical ventilation. |
|---|---|---|
| Lbs. | Fahr. | Yards. |
| 8 | 100° | 960 |
| | 150° | 1040 |
| | 200° | 1130 |
| 10 | 100° | 760 |
| | 150° | 830 |
| | 200° | 900 |
| 12 | 100° | 640 |
| | 150° | 700 |
| | 200° | 750 |

A recent calculation by M. Guibal of Mons, Belgium, gives the following comparative results. If a furnace in a 12 feet shaft 400 yards deep, circulating 53,000 cubic feet of air per minute against a total resistance represented by 3·30 inches water gauge, with an average excess of temperature of 108° Fahr. in the upcast shaft above the downcast, have a consumption of 31 lbs. of coal per hour per horse power in the air, estimated upon the total resistance: then a mechanical ventilator utilising 60 per cent. of the power employed would under the same conditions consume 11 lbs. of coal

per hour per horse power in the air, being a saving of 64 per cent. At a depth of 550 yards, and circulating the same volume of air, the consumption of the furnace would be 22 lbs. of coal, and that of the mechanical ventilator 11 lbs., showing a saving of 50 per cent.

It is not within the scope of this paper to describe all the various Mechanical Ventilators that have been used; these are numerous, but may be classed under two heads, namely those working by centrifugal action and those working as pumps. An opportunity will be afforded during the present meeting of the Institution for inspecting different examples of each of the principal ventilators in the first class. One of these, the Guibal ventilator at Cradley Colliery, Staffordshire, was described at the last meeting of the Institution (see Proceedings Inst. M. E. April 1869, page 78); and the largest example of this plan of ventilator yet erected in this country will be seen at Thrislington Colliery, Ferryhill. It is shown in Figs. 1 to 4, Plates 25 to 27, and is 36 feet diameter and 12 feet breadth, driven by a horizontal cylinder of 30 inches diameter and 30 inches stroke working direct upon a crank on the fan shaft.

This ventilator has only been recently erected, and is not yet ventilating any large extent of workings; but some experiments have been made with it, from which the following results have been obtained. The regulating shutter had not at the time of the experiments been properly adjusted so as to give the best results of working; and the drift into the bottom of the upcast shaft was too small for accurately measuring the current of air, which amounted to about 80,000 cubic feet per minute at the speed of 70 revolutions per minute.

With 54 revs. per min. the water gauge at the inlet was maintained at 2·60 inches.

| | | |
|---|---|---|
| 70 | . . . . . | 4·50 „ |
| „ 80 | . . . . . | 6·25 „ |

At Gethin Colliery, South Wales, with a Guibal ventilator 30 feet diameter and 10 feet width, running at 61 revolutions per minute, a volume of 153,600 cubic feet of air per minute was circulated with a water gauge of 2·60 inches, and 64 per cent. was utilised of the

total steam power supplied from the boilers. Two Guibal ventilators working at Grand Busson near Mons, of 29½ and 23 feet diameter and 6½ and 5½ feet width respectively, furnish instances of the high water gauges under which these ventilators can be worked for the regular ventilation of mines, the water gauges in these cases being 7·40 and 5·12 inches respectively, with the ventilators running at 102 and 112 revolutions per minute.

In order to make a fair comparison of the Guibal ventilator with the furnace, the following case of the Pelton Colliery in the county of Durham is given, as it is one where the data have been accurately ascertained respecting the substitution of this mechanical ventilator in place of the furnace. In this instance the consumption with the furnace was 101·6 lbs. of coal per hour per horse power in the air, estimated on the water gauge of 1·10 inch indicated in the mine with an air current of 36,350 cubic feet per minute, the average upcast temperature being 207°; and the consumption was reduced by the Guibal ventilator of 30 feet diameter and 10 feet width, running at 56 revolutions per minute, to 19·9 lbs. per hour per horse power in the air, with a current of 64,700 cubic feet and a water gauge of 2·05 inches indicated in the same position as previously. This shows a saving of fuel amounting to 80 per cent. by the adoption of the Guibal ventilator in place of the furnace.

In the class of ventilators working upon the principle of centrifugal action, to which the Guibal fan belongs, may be mentioned also the Biram, Nasmyth, Brunton, Waddle, and Rammell ventilators; these are shown in Figs. 9 to 18, Plates 28 to 33.

In the Biram ventilator, which is shown in Figs. 9 and 10, Plate 28, the vanes are inclined backwards to the radius, instead of being truly radial as in the Nasmyth fan (see Proceedings Inst. M. E. April 1869, Plate 8). A Biram fan has been experimented upon by the writer at the Tursdale Colliery in the county of Durham, and it was found that only 12·7 per cent. was utilised of the gross power supplied from the steam boilers; and from experience with other open-running fans it is considered that this percentage cannot be materially exceeded by any similar form of open fan without a casing.

A Waddle ventilator recently erected at Pelton Colliery, shown in Figs. 13 to 15, Plates 30 and 31, utilises only 39 per cent. of the gross power applied; and a Rammell fan at Framwellgate Colliery near Durham, shown in Figs. 16 to 18, Plates 32 and 33, does not utilise more than 40 per cent. of the gross power. The Guibal fan, as will be seen from the experiments afterwards given, utilises 60 per cent. of the gross power. Except the Guibal fan, all the ventilators of this type discharge the air round their entire circumference; but that this is a defect may be inferred from the consideration that if an open-running fan have the access of air into its centre stopped, great power will still be required to make it revolve, though no useful work is done; and the useless work done in this case upon the external air is also done when the fan is exhausting air supplied at its centre from the mine drift, and the useful effect therefore suffers a corresponding diminution. The Waddle ventilator, shown in Figs. 13 to 15, was intended to obviate this defect, by making the air passage through the fan with a gradually decreasing section from the centre to the circumference, so that the velocity of rotation at any distance from the centre multiplied by the sectional area of passage at that distance should be constant, with the view of keeping the fan filled up to its circumference with issuing air, and preventing the possibility of re-entries of air from the external atmosphere. In this case the re-entries are not indeed visible, as they are in the Biram fan where the eddies of the air all round the circumference are easily seen; but that they do actually arise is proved by the low percentage of power utilised with the Waddle fan.

The Brunton fan, shown in Figs. 11 and 12, Plate 29, which closely resembles the Waddle fan, and the Rammell ventilator, Figs. 16 to 18, which may be looked upon as a double Waddle fan, cannot be expected to yield any better results. The Rammell ventilator recently erected at Framwellgate Colliery is working underground at the bottom of the pit; it is 22 feet diameter and is driven by a 20 inch steam cylinder, and the writer has been informed by Mr. Daglish that at 102 revolutions per minute the volume of air circulated was 53,600 cubic feet per minute with a water gauge of 2·15 inches, giving 18 horse power in the air; and the power applied

in the engine was 46 horse power, giving the result of 40 per cent. utilised.

One of the chief reasons of the low useful effect obtained from these exhausting fans is that they are exposed round the entire circumference to the external air, which rushes in behind the vanes to supply the vacuum formed by their revolution. But the air to fill up this vacuum ought to be supplied only from the mine; and it was this consideration, supported by the practical proof that this defect was inherent in open-running fans, which led to the casing-in of the Guibal ventilator and the discharge of the air at only one part of the circumference. This step however was attended with the objection that the air was discharged at the high velocity of the circumference of the fan, and thus carried away with it an important store of force; and the partial utilisation of this force has been effected by making the casing of the ventilator terminate in an expanding chimney A, Fig. 2, Plate 25. By this plan the air entering the base of the chimney at a high velocity is made to leave the top of the chimney at a reduced speed proportionate to the increased area of the outlet, and consequently a considerable amount of power is thereby restored which would otherwise be carried off.

The addition of the adjustable shutter B B, Fig. 3, Plate 26, was next found necessary in order to regulate the size of the outlet from the ventilator according to the various conditions of volume of air required and resistance to be overcome. These conditions vary not only in different mines, but also in the same mine as the workings proceed; and they cannot be determined except by experiment in each individual case. A series of very interesting experiments has been made showing the steadily improved results obtained from the Guibal ventilator, as the casing, chimney, and shutter with its accurate adjustment, were successively added. The following results were obtained as an average of experiments made at a mine in Belgium with the ventilator running at low and high speeds:—

| | | |
|---|---|---|
| *Without* the casing . . . | the useful effect obtained was | 22 per cent. |
| *With* the casing . . . . . | 31 | ,, |
| With casing and expanding chimney . . . . | 57 | ,, |
| Do. with shutter adjusted . . . . . | 61 | ,, |

Out of the gross power supplied from the steam boilers for working these ventilators 60 per cent. is generally found to be utilised; and this amounts to as much as 80 per cent. of the net power actually transmitted to the ventilator, because one fourth of the boiler power has to be allowed for the loss due to the friction and imperfections of the steam engine.

Several Guibal ventilators are now in use in this country of 36 feet diameter, and one has recently been started in Belgium of 40 feet diameter, with which at a speed of 47 revolutions per minute a vacuum of 2·87 inches water gauge has been attained, and at 55 revolutions 3·89 inches. This ventilator is arranged to work at the speed of 80 revolutions per minute, and is capable of producing a ventilation of 150,000 to 200,000 cubic feet of air per minute with about 7 inches water gauge, which is certainly the maximum requirement of any known conditions in mines. Indeed there can be no question that any practical requirements in the ventilation of mines can be satisfied by the Guibal fan; and it cannot be surpassed in simplicity of construction, freedom from liability to accident, and the small amount of wear and tear to which its working parts are subjected.

The peculiarities in the construction of the Guibal ventilator have been the subject of discussion at the previous meeting of this Institution; and the two following important points that were raised deserve special consideration.

First, as to the concentric form of the casing. The spiral form of casing was adopted for the first Guibal ventilator, on account of its being the form generally adopted for blowing fans. Further experiments however, which have been carefully made in the development of the Guibal ventilator, are understood by the writer to have proved the spiral casing to be incorrect both for exhausting and for blowing fans; and the concentric casing was found to give the best results. An apparent reason for this is, that the more removed the casing is from the extremities of the vanes, the less proportion of the total air in the casing is driven directly by the vanes, and consequently the less effective result is obtained from the centrifugal

force. The idea that with a spiral casing the air which is drawn into the ventilator at the centre finds a free discharge at all points of the circumference of the vanes does not appear to be an accurate representation of the action of the fan. The course of a particle of air leaving the centre is indicated by the dotted lines in the accompanying diagrams, Figs. 5 and 6, Plate 28. The particle A for instance, describing the course A B, finds at B an unresisted outlet; but the particle C impinging on the casing at D has only an indirect escape; and the particle E cannot be discharged at all from the casing at F. The consequence is that from B to F and from F to D the air between the casing and the circumference of the vanes is kept confined a longer time in the spiral casing, and thus loses a portion of its velocity of rotation; so that it cannot have the same effective impulse at the circumference nor produce the same exhaustion at the centre of the fan. This view is opposed to that most generally entertained upon the subject; but the writer understands it is fully supported by the results of the extensive experiments that have been carefully made by M. Guibal at Mons for the purpose of testing the different forms of casing which have been tried in the development of the present Guibal ventilator.

Secondly, as to the curving of the vanes. Any backward curvature of a vane tends to reduce the effect of centrifugal force in propelling the air; for a particle of air following the curve G H in the diagram Fig. 7, instead of the line of the radius G I, is left by the distance I H behind the point where it would otherwise have been when arriving at the circumference. Any such curvature would only be applicable for the purpose of reducing the loss of power arising from the ultimate tangential velocity in the air when discharged all round the circumference from an open fan; and for blowing fans such a form is opposed to the object aimed at. In the Guibal ventilator a forward curvature of the extremity of the vanes is adopted, for the purpose of correcting the injurious effect thus resulting from the inclination of the vanes backwards, as shown in the diagram Fig. 8: the inclination K L backwards from the radial line K M being designed to avoid the

blow that would be produced by the entering air upon the vane at K if the vane were placed radially. If however the inclined vane were extended to L, a loss measured by M L would be caused in the velocity of rotation of the air; and this is reduced to M N by the curvature forwards of the extremity of the vane.

In the class of mechanical ventilators which act upon the principle of a pump, the best known example in this country is Struvé's ventilator (see Proceedings Inst. M. E. April 1869, Plate 8), which consists of two large pistons formed like gasometers, working in annular troughs of water; the alternating upward and downward strokes draw in air from the mine and discharge it into the atmosphere by means of suitably arranged flap-valves. A horizontal arrangement of this ventilator, having a pair of pistons supported by wheels working on rails, has been applied at Nixon's Navigation Pit near Aberdare; but the sources of leakage in this case must evidently be much greater than with the vertical arrangement where a water joint can be used. The flap-valves in either case must be so numerous, in order to get sufficient area of inlet and outlet opening for the air, that they present constant sources of leakage and are costly to maintain; while the apparatus must be of such large dimensions, where any considerable current for ventilation is required, that the maximum speed at which it can be safely and economically worked is soon reached, and a liability to derangement ensues which interferes with the certainty of the ventilation. This ventilator, when well constructed and in good order, is capable of producing a very satisfactory exhaustion, although for the above reasons it does not offer the advantages for mine ventilation which the centrifugal fan presents. The useful effect is from 40 to 45 per cent. of the gross boiler power, when all working parts and especially the air valves are in good condition. The Fabry ventilator and others little known in this country, but much used till recently on the continent, are of the same type, and in ordinary work do not exceed 35 per cent. utilised of the gross power applied; and the same objections apply to them as to the Struvé ventilator.

The principle of a rotary pump is adopted in the Lemielle ventilator, which is employed at the Page Bank Colliery, South Brancepeth, and the Washington Colliery, both in the county of Durham. The one at Page Bank Colliery is the largest ventilator hitherto erected of this construction, being 23 feet diameter and 32 feet height; and it is shown in Figs. 19 and 20, Plates 34 and 35. It consists of a vertical drum A revolving eccentrically within a cylindrical chamber B, and carrying three vanes C hinged upon it, the outer extremities of which are guided by radius rods D from a concentric fixed shaft E so as to work close to the circumference of the chamber all round. By the revolution of the drum variable spaces are thus formed between the vanes, the largest coming between the outlet passage G and the drift F leading from the mine, as shown in the plan, Fig. 19; and the vanes acting like successive pistons draw in the air from the mine at F and discharge it at G into the atmosphere.

The useful effect of the Lemielle ventilator is low, averaging only $35\frac{1}{2}$ per cent. of the gross boiler power at the Page Bank Colliery, where a volume of 60,000 cubic feet of air per minute is exhausted from the mine under a resistance of 2·65 inches water gauge, the ventilator making 10 revolutions per minute, which may be considered a fair working speed. The consumption of coal is 41 lbs. per hour per horse power in the air. At $16\frac{1}{2}$ revolutions per minute the volume of air circulated is 97,000 cubic feet per minute with 6·65 inches water gauge. The difficulty however of obtaining a sufficiently close contact of the vanes with the circumference of the chamber, the numerous joints, and the large slots necessary in the drum to allow for the working of the radius rods, present sources of leakage in this construction of ventilator which it seems impracticable to overcome. Although the Page Bank ventilator is most carefully constructed in these respects, yet the re-entries of air in a special experiment, where the resistances of the mine were reduced considerably below those of its ordinary working condition, were shown to be as much as 29 per cent. of the theoretical quantity which ought to be discharged from the mine according to the calculated total displacement produced by the

revolving vanes; and this loss becomes increased to 43 per cent. when the ordinary resistances of the mine are encountered. The extent of the leakage forms indeed the serious defect of the Lemielle ventilator. Tight joints, such as are obtained in the cylinder and piston of a blast engine, cannot be secured in a ventilator of this construction and magnitude; and as the resistances increase under which the air has to be drawn from the mine, the re-entries from the leakages increase in proportion to the square root of the resistances, the air from the external atmosphere following each vane as it passes the outlet.

The details of construction of the Lemielle ventilator, which have been carefully arranged in the two examples at the Page Bank and Washington Collieries, are still such as to render it very inferior in a mechanical point of view to the centrifugal ventilators, where only two main bearings are required; while in the former there is a complicated system of joints, hinges, and collars, with a turntable arrangement of wheels and rails to relieve the bottom pivot of the great weight which it would otherwise have to carry. There is consequently a greatly increased liability to accident, more wear and tear, and a larger consumption of stores and labour; and moreover if a breakdown of the machinery should occur, the ventilation would immediately be stopped altogether, by the ventilator then acting as a stationary piston, completely blocking up the outlet passage from the mine. The slow speed also at which this heavy machinery must work (14 revolutions per minute being found a maximum with the Page Bank ventilator), and the absence of any flywheel, give rise to serious strains at the dead points of the stroke of the engine.

In conclusion, it may be remarked that the economy of fuel in ventilation of mines, if neglected hitherto, has now become of paramount importance. To increase the amount of air in any given mine requires the consumption of an increased quantity of fuel proportionate to the cubes of the volumes, so that twice the volume of air requires eight times the fuel. Hence the best system of ventilation is that, which, under the same conditions of mine and at the same amount of first outlay, produces the maximum useful

effect per lb. of coal consumed: so long as it compares satisfactorily with any other system in respect to durability and cost of working, and is also capable of being adapted to all the varying conditions that are met with in mining operations.

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Mr. A. L. Steavenson remarked that the principle of centrifugal action, which was advocated in the paper for the purpose of ventilating mines, was not found suitable for other applications where the pressure to be produced was great, as in the case of blowing blast furnaces, or raising water by the suction of a centrifugal pump; and it had appeared to him therefore that the principle of varying capacity, as exemplified by the cylinder and piston of a blowing engine or of an ordinary pump, would be the one most advantageous also for producing the current of ventilation in a mine. On this account he had preferred at the Page Bank Colliery to recommend the adoption of the Lemielle ventilator that had been referred to in the paper, acting in the manner of a revolving pump; and although no doubt that construction of ventilator was open to objections such as had been advanced respecting it, the Guibal ventilator was also attended he considered with objections, notwithstanding that in ordinary working it was found to give good results in the proportion of power utilised. He hoped that further improvements would yet be introduced in the appliances for mine ventilation, so as to render them superior both in mechanism and in useful effect to any of the ventilators at present in use.

Mr. J. S. E. Swindell said that the Guibal ventilator at the Homer Hill Colliery, Cradley, of which he had given a description at the previous meeting of the Institution, had now been running continuously for upwards of twelve months, and he had never had any cause to complain of its working in any way whatever. The whole construction of the ventilator seemed to him to be as simple

as it well could be; there were only two bearings, and there was consequently nothing to get out of order; and the ventilator had never cost anything whatever in the way of repairs. The usual speed of working was about 26 revolutions per minute, the ventilator being $16\frac{1}{2}$ feet diameter and $4\frac{3}{4}$ feet wide; but he had recently for a trial run it at 124 revolutions per minute, when the quantity of air passing through it was 40,000 cubic feet per minute with a water gauge as high as 3·15 inches in the fan drift. He was able to express entire satisfaction with the way in which the Guibal fan had done its work at his own colliery, and he certainly considered it the best ventilator at present in use.

Mr. E. A. Cowper observed that he could not agree with the conclusions which had been arrived at in the paper with respect to the construction of the casing and the vanes of the Guibal ventilator, because in the experiments which he had made upon blowing fans, as named in the discussion at the previous meeting, he had found that, by the adoption of properly proportioned dimensions, the useful effect obtained from a blowing fan with a spiral casing, giving a continuously increasing space beyond the tips of the fan vanes from nothing up to the full area of the discharge aperture, and with straight radial vanes, was raised from 37 to as much as 75 per cent. of the power put into the fan shaft by the engine driving it. Those experiments had been very numerous and carefully conducted, and in each trial indicator diagrams were taken from the engine driving the fan, and the pressure of blast in the delivery main from the fan was ascertained near the delivery by a water gauge. The friction of the engine and shafting, as ascertained by corresponding indicator diagrams taken with the fan disconnected, was then deducted from the power shown by the indicator diagrams with the fan, so as to give the net power consumed by the fan; and the useful effect was estimated from the quantity of blast delivered, calculated from the pressure observed in the delivery main and the theoretical velocity due to that pressure, multiplied by the area of all the discharge openings. In this way the result had been arrived at of 75 per cent. useful effect out of the net power put into the fan, with the casing having the spiral form described. He did

not think that the spiral form for the casing was shown to be incorrect by contemplating the line of motion of any individual particle of air: on the contrary he did not see any means of providing for the continual swelling of the volume of air in the casing, occasioned by the discharge of successive infinitesimal laminæ of air round the whole circumference of the fan, except by adopting the spiral form of casing so as to obtain a continually increasing space round the fan; and it was only when this was done, he considered, that the vanes of the fan were all able to produce their full effect in discharging the air, which then left the tips of the vanes at about 9-10ths of their circumferential velocity.

Mr. W. Cochrane did not think the plan of calculating the quantity of air delivered from the theoretical velocity due to the pressure observed would give sufficiently accurate results, and he considered it might lead to material error. The only satisfactory way he thought was to measure the actual velocity of the air by means of a carefully tested anemometer; and this was the course he had adopted in the trials of different ventilators. The result obtained in this way from the Guibal fan had been found to be that 60 per cent. was utilised of the gross power supplied to the engine from the boiler, as shown by the steam line of the indicator diagrams taken from the engine, without deducting the back pressure of the exhaust; so that the useful effect of the net power put into the fan shaft, after allowing for the friction and back pressure of the engine, would amount to more than the 75 per cent. that had been named, on the supposition that the net effective power of the engine would not be more than three quarters of the gross power supplied to it in the steam from the boiler, which he thought might reasonably be assumed. With the spiral form of casing, it appeared to him that the particles of air discharged from the circumference of the fan at some distance back from the delivery orifice could not have so great a velocity by the time they reached that orifice as at the moment of leaving the tips of the vanes, on account of having lost the direct propelling effect of the vanes; and this would therefore be the cause of a loss of power in the employment of the spiral casing.

Mr. A. L. Steavenson observed that in the discharge of the air from the Guibal fan an expanding chimney was used for reducing the velocity of the air before its discharge into the atmosphere, and he thought the expanding spiral casing that had been described would have a similar effect in retarding the air before it reached the discharge orifice of the fan casing. If however the principle of centrifugal action was so advantageous as was represented for the ventilation of mines, he did not understand why the fan was not employed also for supplying the blast to blast furnaces.

Mr. W. Cochrane replied that in mine ventilation the greatest amount of vacuum required to be produced by the fan did not exceed 6 or 8 inches of water; but in the case of blast furnaces the pressure of blast now required was often not less than 70 inches of water, which it was impracticable to obtain by a fan, the principle of the fan being only applicable with advantage for comparatively low pressures of air.

Mr. D. P. Morison said he had had an opportunity of seeing the Guibal fan at work in Belgium, where it was extensively employed for ventilating mines, and he had ascertained that the experience of its working had established the useful effect as amounting to 83 per cent. of the net power communicated to the fan shaft; and the vacuum maintained by a fan of 30 feet diameter, running at 102 revolutions per minute, was $7\frac{1}{2}$ inches water gauge. The effect of a spiral casing he thought must be that the air on leaving the tips of the vanes would lose the impulse received from them, and would arrive at the discharge orifice with a diminished velocity, involving a loss of power; but there did not appear to be an analogy between a spiral casing and the widening chimney of the Guibal fan, because the retarding effect of the latter was exerted upon a definite volume of air entering at the bottom only, whereas the spiral casing of a fan received additional volumes of air continuously round the whole circumference of the fan, so that no expansion took place in the casing to retard the velocity of the air, the retardation arising only from the vanes losing their hold upon the air in that construction of casing.

The PRESIDENT enquired what was the rate of increase in the power required to drive the fan for producing an increased amount of ventilation in the mine.

Mr. W. COCHRANE replied that the resistances to the current of ventilation through the passages of a mine increased as the square of the velocity of the current; but the power required to drive the fan increased as the cube of the velocity of current, because at double the velocity, not only was the resistance to the passage of the air four times as great, but also double the quantity of air was drawn through the mine in the same time under this quadrupled resistance, requiring therefore eight times the power.

The PRESIDENT observed that, whatever difference of opinion there might be as to the comparative merits of the different forms of fans now in use, there could be no question that the application of mechanical power for the purpose of ventilating mines was superior to the method of ventilating by a furnace, and that mechanical ventilation would become more and more important every year, because it was clear that coal mines in future would have to be sunk to a much greater depth than at present. The fact of working at a greater depth involved also working to greater distances from the shaft; because the expense of sinking a deep shaft was so great, that in order to repay it a large tract of coal must be worked, and the passages must be extended to remote parts of the mine. This involved increased difficulty of ventilation, in consequence of the increased resistance to the air current, and the difficulty could only be overcome by the application of mechanical means. Not only in reference to deep mining was mechanical ventilation important, but also in a still higher degree in reference to the deplorable accidents which had become so frequent in coal mines; and there did not appear to be any possible means of diminishing the frequency of these disastrous explosions except by improved ventilation, such as could now be obtained by mechanical ventilators. Independent of the special construction of any particular fan, there were certain requirements which every good fan should satisfy:—namely, a small amount of inward draft from the external air, a small amount of leakage and of eddying action within the fan itself, and a low velocity

of the discharged air. The subject of mechanical ventilation had been brought forwards in a very useful form in the paper now read, in which the results were given of a number of ventilators of different constructions now employed in this country, which would serve as valuable data for the further investigation of the various questions involved in the different plans.

He proposed a vote of thanks to Mr. Cochrane for his paper, which was passed.

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The following paper was then read:—

# ON THE MECHANICAL FIRING OF STEAM BOILERS.

By Mr. JOHN DAGLISH, of Seaham.

The object of the present paper is to give the results of a number of experiments recently made by the writer upon the Firing of Steam Boilers at collieries, both with the ordinary mode of hand-firing, and with different descriptions of mechanical apparatus for the purpose. The experiments were made at three collieries in the county of Durham, the first series being made at Rainton Colliery, where the boilers are fired with Juckes' mechanical furnace, and are some of them also fitted with side waterboxes. A second series were conducted at Seaham Colliery, where three systems of mechanical firing are all in practical operation on the same range of boilers, side by side with the ordinary hand-firing. A third series of experiments, made at Silksworth Colliery, were for the purpose of determining the relative advantages for colliery engines of the internally-fired Cornish boiler as compared with the externally-fired plain cylindrical boiler, prior to erecting a large number of boilers for the extensive new coal winning which is now proceeding at Silksworth. The particulars of the three series of experiments are given in the appended Tables I to VII, and an abstract of the whole in Table VIII.

The first series of experiments was made on the boilers of the pumping engine at Rainton Colliery, which are well adapted for experiments of this kind, as the engine is constantly going and at a nearly uniform speed. The boilers are in one range, five in number, as shown in Figs. 1 and 2, Plate 36; and are all of the same size, 37 feet long and 6 feet diameter, working at a pressure of 30 to 35 lbs. per square inch; they are ordinary egg-ended cylindrical boilers, set with "flash" flues. The boilers Nos. 1, 2, 3, and 5 are covered with a

composition consisting of hair, charcoal, and coal dust; No. 4 boiler is not covered at all. There are constantly four of the boilers at work, one being laid off for repairs and cleaning as required.

All five boilers are fitted with Juckes' self-feeding mechanical firegrate, which has been in operation for some time in this district, and has lately been extensively adopted at many collieries in the North of England. It is shown in Figs. 6 to 9, Plates 37 to 39, and consists of an endless web or chain of short longitudinal firebars A A, traversing forwards with a slow continuous motion, and thus gradually carrying the fuel forwards from the hopper B by a self-acting operation. The chain of bars passes round the drums C C at either end of the furnace, and is supported through the intervening distance by the series of carrying rollers D D. The entire grate is carried in a frame E, which is mounted on wheels F running on rails; so that this arrangement has the special advantage of allowing the whole of the grate and the fire to be withdrawn altogether from under the boiler at any time without any difficulty. The firegrate is 6 feet long and 4 feet broad, giving 24 square feet area; and at the inner end under the furnace bridge G are two wrought-iron pipes H, 2 inches diameter, placed $1\frac{1}{2}$ inch above the grate bars, for the purpose of preventing any pieces of fuel of larger dimensions from being carried over at the end of the grate; these pipes being exposed to the heat of the furnace are kept filled with water from a cistern, in order to prevent them from being burnt. In the case of Nos. 3, 4, and 5 boilers, side waterboxes are added, extending the entire length of the firegrate on each side; these are made of wrought-iron plates, $\frac{1}{2}$ inch thick, and are each 7 inches square by 6 feet long; each is connected to the boiler by a 2 inch pipe at each end, and has a sludge pipe at the outer end for blowing off sediment. The height of the bottom of the boiler above the firebars is 2 feet in Nos. 1, 2, and 5; and 1 ft. 6 ins. in the two other boilers. The usual speed of the forward traverse of the firebars is from 9 to 12 feet per hour, varying with the quality of the coal used and the thickness of the fire; as the object to be attained is that the coal should be just consumed by the time it arrives at the bridge.

The description of coal used in the experiments at Rainton Colliery was entirely refuse or slack of the kind known as "peas," that is, screened small steam coal of about the size of peas; and the same quality and description of coal was used in the experiments upon each boiler at this colliery. The coal itself was of a non-bituminous or open-burning quality, and contained a large percentage of ash; the peas were also largely intermixed with slates, pyrites, &c., and not having been well screened contained a large percentage of dust. The exact quantity of coal consumed under each boiler and the time taken in burning it were noted, and the quantity of water evaporated by the boiler during that time was ascertained by two water meters to avoid error, the feed water supplied by the donkey pump being at a temperature of 45° Fahr.; and the number of strokes made by the engine during each experiment was taken by a counter.

The particulars of these experiments are given in the appended Table I, and the general results are as follows, showing the quantity of water evaporated per hour and also the evaporation per lb. of coal consumed:—

| | Water evaporated. | |
|---|---|---|
| | Per hour. | Per lb. of coal. |
| | Gall. | Lbs. |
| *With* boiler covering, but *without* side waterboxes | 243 | 4·69 |
| *Without* boiler covering, but *with* side waterboxes | 249 | 4·84 |
| *With* boiler covering, and *with* side waterboxes | 267 | 5·33 |

The advantage of the waterboxes at the sides of the firegrate, in increasing the evaporative power of a boiler as well as the economic effect of the fuel, is therefore considerable. This advantage however is to a great extent neutralised by the difficulty and increased expense of maintaining them; but there may be circumstances where their use would be attended with ultimate economy.

The second series of experiments was made on the range of four boilers of the winding engine at Seaham Colliery, shown in the plan, Fig. 3, Plate 36. These are ordinary egg-ended cylindrical boilers,

$7\frac{1}{2}$ feet diameter and 33 feet total length, working at 12 lbs. pressure of steam. They are under cover of a boiler house, and are set with a straight "flash" flue, going direct into the main flue; the chimney is 70 feet high. The temperature of the feed water supplied to the boilers was 60° Fahr. The peas coal used in these experiments consisted of the screenings of caking or bituminous coal; and although containing much ash, and largely intermixed with slates and pyrites, was somewhat cleaner than that used in the preceding experiments at Rainton.

No. 1 Boiler was Hand-fired, and was in the first instance set with a "wheel" flue, passing along underneath the boiler and returning by a side passage, travelling round the boiler before entering the chimney. After the experiments had been made with this wheel flue, as recorded in the first part of the appended Table II, the flue was altered to a straight flash flue, and the further experiments then made are given in the second part of Table II.

No. 2 Boiler was first Hand-fired, and was afterwards fitted up with Stanley's self-feeding mechanical furnace, which is shown in Figs. 10 to 13, Plates 40 and 41. In this apparatus a pair of feeding rollers J J are placed at the bottom of the hopper B, for the purpose of crushing the coal to a uniform small size; and the coal passing between them falls upon the two dispersers K K, Figs. 12 and 13, which are rapidly revolving discs having radiating arms that scatter the coal over the whole surface of the fire by centrifugal action, as shown in Fig. 11. The dispersers are driven at a speed of 236 revolutions per minute, revolving from each other, right and left. The experiments with this furnace are given in Table III appended.

No. 3 Boiler was fired with Vicars' self-feeding mechanical fire-grate, which is shown in Figs. 14 to 19, Plates 42 and 43. A regular supply of coal is here pushed forwards upon the front end of the firegrate by the alternate action of a pair of feeding plungers L L at the bottom of the hopper B, Fig. 14, having a very slow motion; and the firebars M have an intermittent longitudinal reciprocating motion imparted to them from the two cam shafts N and P, Figs. 16 to 18, which are geared together by equal pinions, and are rotated at a very slow speed by the ratchet-wheel R. The

forward shaft N by means of the rod S advances the whole of the firebars simultaneously a distance of 3 inches; the incandescent fuel upon the firegrate is thus carried forwards through that distance, and then remains stationary during the rest of that revolution of the cam shaft, and the average rate of advance is about 10 feet per hour. The return motion of the firebars is effected by the projecting arms T upon the backward cam shaft P, but these arms are so arranged as to withdraw only every third bar simultaneously, while the intermediate bars are held stationary by the cams U and V upon the forward cam shaft N, Figs. 17 and 18; the whole of the firebars are thus withdrawn in three successive stages, without carrying back the fuel with them. Each end of the firebars is carried upon a small loose roller I, Figs. 16 and 17, to facilitate the movement of the bars in their forward and backward traverse. The firebars are perforated with numerous air channels, as shown in Figs. 15 and 19, for the purpose of admitting a sufficient supply of air for burning the very smallest description of coal, known as "duff" or dust coal, which is the dust from the screening of the "peas." The underside of each firebar is immersed in a water trough, as shown in Figs. 16 and 19, which is kept constantly filled with a continuous supply of cold water flowing in from the transverse pipe W, Fig. 16, for the purpose of cooling the firebars, as no ordinary firebars can withstand the intense heat of this fire. The experiments made with this mechanical firegrate are given in Table IV appended.

No. 4 Boiler was fired with Juckes' self-feeding mechanical furnace, of similar construction to those previously experimented on at Rainton Colliery, shown in Figs. 6 to 9, Plates 37 to 39, but without the side waterboxes used at Rainton; and the firegrate was of rather larger dimensions, being $6\frac{1}{2}$ feet long and $4\frac{1}{2}$ feet broad, giving $29\frac{1}{4}$ square feet area. The experiments made at Seaham with this furnace are given in Table V appended.

From the experiments made with Hand-firing, as recorded in Table II, it appears that the quantity of water evaporated per lb. of coal with a flash fine is 6·69 lbs. as compared with 5·03 lbs. with a

wheel flue; and the total quantity of water evaporated is 428 gallons per hour with the flash flue as compared with 289 gallons per hour with the wheel flue: showing a marked advantage in the flash flue over the wheel flue, not only in economic effect of fuel, but also in economy of boiler space in consequence of more rapid generation of steam. It is probable however that the high economic effect here obtained of 6·69 lbs. of water evaporated per lb. of coal is considerably above that realised under ordinary circumstances, as the firing of this boiler was more regularly attended to than is usual in hand-firing.

The experiments with the Stanley furnace, Plates 40 and 41, gave very irregular results, as seen in Table III, showing that a lengthened series of experiments as to speed of the dispersers, thickness of fire, &c., would be required before the maximum effect could be regularly attained. As compared with Hand-firing, a much lower average economic effect is exhibited, being 4·74 lbs. of water evaporated per lb. of coal, instead of the 6·69 lbs. with hand-firing (Table II); but it is more than probable that this arose from the mechanical apparatus not having been in all respects so arranged as to produce its maximum effect. The special advantages of this furnace are that it permits of the use of "duff" or dust coal, and that a comparatively large amount of fuel can be consumed per square foot of firegrate surface: it is not perfectly effectual however in the prevention of smoke.

Of the several mechanical appliances tried by the writer for firing steam boilers, none appears to be so successful as the Vicars mechanical furnace, Plates 42 and 43, as arranged at Seaham Colliery; though the same apparatus erected elsewhere seems not yet to have been so successful: this is probably owing however to the improvements recently made in the apparatus, and employed at the Seaham furnace, which has been in constant operation for nine months without requiring any repairs; and in all respects it has been most successful and economical, and is very efficient in preventing the production of smoke. From Table IV it is seen that when using "peas" coal, the same quality as in the experiments with hand-firing (Table II), the economic effect was 7·15 lbs. of water evaporated per

lb. of coal, in comparison with 6·69 lbs. by hand-firing; but as the high amount was in one instance attained of 8·79 lbs. of water evaporated per lb. of coal, it is probable that the maximum results of this furnace have not been yet obtained, nor the best thickness of fire yet ascertained. The great advantage however attending the use of this furnace consists in its being applicable for burning "duff" or dust coal with high economic effect. The average duty with this fuel, as shown in Table IV, was 6·84 lbs. of water evaporated per lb. of coal, and in one experiment was as high as 7·70 lbs. of water per lb. of coal, the firebars being then driven at their minimum speed. The average consumption of fuel in one of the Seaham boilers being about 5 tons per day of 24 hours, and the respective prices of "peas" and "duff" coal about 3*s.* and 1*s.* per ton at the pit, the commercial economy effected by the use of this furnace over any other mechanical apparatus not adapted for burning duff coal appears to be more than £150 per year per boiler. The rapidity of evaporation in these experiments does not appear to be equal to that with the Juckes firegrate or with Hand-firing, although this may arise from the fact of the capabilities of this furnace not being yet fully developed. The firebars used in the Vicars furnace at Seaham are 4 ft. 8 ins. long, whilst those in the Juckes furnace are 6 ft. 6 ins. long; but although the heat of the fire in the shorter grate was much more intense than in the longer, yet the pyrometer observations in the flue beyond the boiler showed a lower temperature throughout from the shorter grate than from the longer. It would seem therefore that the heat developed on the grate of the Vicars furnace is of considerably higher intensity than in the Juckes furnace, and is therefore more effectual in its action upon the exposed surface of the boiler, so that there is less waste heat passing off into the flue.

The advantages of the Juckes furnace, shown in Plates 37 to 39, are perfect avoidance of smoke, great regularity in raising steam, and the saving effected by this mode of mechanical firing, in common with other mechanical appliances for the same purpose, both in the wear and tear of boilers and in the manual labour of stoking, the latter saving alone amounting probably to £25 per year per boiler,

when the fuel can be tipped into the hoppers from a higher level. In comparison with Hand-firing it does not seem to possess any great advantage in economy of fuel, the average economic effect shown in Table V being 5·90 lbs. of water evaporated per lb. of coal as compared with 6·69 lbs. in hand-firing; but the latter, as previously remarked, is probably a considerably higher result than is usually attained in practice. Like all other mechanical appliances the Juckes furnace requires a certain amount of care and attention in its use; but on the whole it may be said to be successful and economical in application. It is not well adapted however for burning "duff" or dust coal, although this is done in some instances where the duff is washed.

The third series of experiments was made on a pair of single tubular boilers erected for temporary purposes at Silksworth Colliery, and shown in Figs. 4 and 5, Plate 36. They are Hand-fired, and are each 30 feet long and 6 feet diameter, with a single tube 2 ft. 6 ins. diameter; and the tops of the boilers are not covered. These boilers had previously been in use at the Londonderry blast furnaces, Seaham, supplying steam to the blowing engine; and they were there each set over the firegrate, the draught returning through the tube and thence round each side of the boiler to the chimney. In these experiments one of them was set in a similar way, and fired externally, as shown in Fig. 5; while the other was used as a Cornish boiler, having a firegrate fitted up inside the tube. The experiments on these boilers were intended also to show the useful effect of external heating surface; for which purpose the dampers of each boiler were so arranged that the draught could either be taken at once up the chimney, or made to pass round the outside of the boiler by an external wheel flue. The coal used was "peas" coal similar to that used in the experiments at Seaham Colliery, but somewhat inferior in quality.

The particulars of these experiments are given in Tables VI and VII, and the following are the chief deductions to be drawn from them. In the internally fired boiler (Table VI) the advantage of using the wheel flue over taking the draught direct from the

tube to the chimney is as 5·51 to 4·87. But in the externally fired boiler (Table VII) the use of the wheel flue instead of taking the flame direct from under the boiler to the chimney is attended with a slight disadvantage, in the proportion of 4·72 to 4·96; and this result tends to show the advantage of flash flues having a large heating surface. The most important point however to be deduced from these experiments is the small evaporative power of a boiler fired through a single small tube with a low draught, as compared with a boiler fired underneath, the rate of evaporation being only 100 gallons of water per hour by the former method, in comparison with 207 gallons by the latter.

The chimney used for these boilers was only temporary and not capable of producing a draught sufficient for the wheel flues, the vacuum at the bottom of the chimney being less than 0·1 inch water gauge; which renders it impossible to make any comparison between these experiments and those tried at Seaham Colliery. As moreover these two boilers at Silksworth are by no means fair specimens of Cornish boilers, arrangements are being made to carry out a further series of experiments with boilers of improved construction recently erected at Hetton Colliery, for the purpose of ascertaining the evaporative power and economy of the Cornish boiler as compared with the plain cylindrical boiler.

## TABLE I.

*Experiments at Rainton Colliery, with Juckes' Mechanical Furnace (Plates 37 to 39).*
*Plain cylindrical Boilers, with flash flues. "Peas" (screened small) Coal.*

| Description of Boiler. | No. of Expt. | Duration of Experiment. | Engine Strokes per hour. | Water Gauge in Chimney. | Coal consumed. | | | Water evaporated. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Total. | Per hour. | Per sq. ft. of grate per hour. | Total. | Per hour. | Per lb. of coal. |
| | No. | Hrs. Mins. | | Inch. | Lbs. | Lbs. | Lbs. | Gall. | Gall. | Lbs. |
| No. 1 Boiler, with top covering, without side waterboxes. | 1 | 12 10 | 311 | ... | 6692 | 550 | 22·9 | 3150 | 259 | 4·71 |
| | 2 | 12 40 | 295 | ... | 7056 | 557 | 23·2 | 3250 | 257 | 4·61 |
| | 3 | 12 20 | 303 | ... | 7548 | 612 | 25·5 | 3200 | 259 | 4·24 |
| No. 2 Boiler, with top covering, without side waterboxes. | 4 | 13 0 | 302 | 0·30 | 6832 | 526 | 21·9 | 3300 | 254 | 4·83 |
| | 5 | 14 10 | ... | 0·30 | 6328 | 447 | 18·6 | 3100 | 219 | 4·90 |
| | 6 | 14 40 | ... | ... | 6832 | 466 | 19·4 | 3200 | 218 | 4·68 |
| | 7 | 13 45 | ... | ... | 6720 | 489 | 20·4 | 3250 | 236 | 4·84 |
| | Averages | 13 15 | ... | ... | 6858 | 521 | 21·7 | 3207 | 243 | 4·69 |
| No. 3 Boiler, with top covering, with side waterboxes. | 8 | 13 20 | 301 | 0·30 | 6748 | 506 | 21·1 | 3450 | 259 | 5·11 |
| | 9 | 13 0 | ... | 0·30 | 6524 | 502 | 20·9 | 3400 | 262 | 5·21 |
| | 10 | 13 50 | ... | 0·30 | 6888 | 498 | 20·7 | 3330 | 241 | 4·84 |
| | 11 | 12 40 | ... | 0·30 | 6804 | 537 | 22·4 | 3350 | 264 | 4·92 |
| | Averages | 13 12 | ... | 0·30 | 6741 | 511 | 21·3 | 3382 | 256 | 5·02 |
| No. 4 Boiler, without top covering, with side waterboxes. | 12 | 13 20 | 265 | 0·30 | 7280 | 546 | 22·7 | 3300 | 247 | 4·53 |
| | 13 | 13 40 | 315 | 0·30 | 6916 | 506 | 21·1 | 3300 | 241 | 4·77 |
| | 14 | 15 12 | ... | 0·35 | 7588 | 499 | 20·8 | 3950 | 260 | 5·21 |
| | Averages | 14 4 | ... | 0·32 | 7261 | 517 | 21·5 | 3517 | 249 | 4·84 |
| No. 5 Boiler, with top covering, with side waterboxes. | 15 | 13 0 | ... | 0·30 | 6860 | 528 | 22·0 | 3650 | 281 | 5·32 |
| | 16 | 12 30 | ... | 0·30 | 5964 | 477 | 19·9 | 3450 | 276 | 5·78 |
| | 17 | 13 40 | ... | 0·30 | 6804 | 498 | 20·7 | 3480 | 255 | 5·11 |
| | 18 | 13 35 | 271 | 0·30 | 6860 | 505 | 21·0 | 3500 | 258 | 5·10 |
| | Averages | 13 11 | ... | 0·30 | 6622 | 502 | 20·9 | 3520 | 267 | 5·33 |

Height of boiler above firegrate, Nos. 1, 2, and 5 boilers, 2 feet; Nos. 3 and 4 boilers, 1 ft. 6 ins. Speed of Firebars 9 to 12 feet per hour. Area of Firegrate in each of the boilers 24 square feet. Thickness of Fire at front of grate 3½ to 4 inches.

## TABLE II.

*Experiments at Seaham Colliery. Hand-Firing with Wheel Flue and Flash Flue.*
*No. 1 Boiler, plain cylindrical. "Peas" (screened small) Coal.*

| Description of Flue. | No. of Expt. | Duration of Expt. | Engine Strokes per hour. | Water Gauge in Chimney. | Pyrometer in Flue. | Coal consumed. | | | Water evaporated. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Total. | Per hour. | Per sq. ft. of grate per hour. | Total. | Per hour. | Per lb. of coal. |
| | No. | Hours. | | Inch. | Fahr. | Lbs. | Lbs. | Lbs. | Gall. | Gall. | Lbs. |
| Wheel Flue. | 1 | 6 | 434 | 0·45 | ... | 3674 | 612 | 27·2 | 1900 | 317 | 5·17 |
| | 2 | 6 | 452 | 0·40 | ... | 3236 | 539 | 24·0 | 1700 | 283 | 5·25 |
| | 3 | 6 | 551 | 0·40 | ... | 3425 | 571 | 25·4 | 1600 | 267 | 4·67 |
| | Averages | 6 | 479 | 0·42 | ... | 3445 | 574 | 25·5 | 1733 | 289 | 5·03 |
| Flash Flue. | 4 | 6 | 602 | 0·45 | 650 | 4022 | 670 | 29·8 | 2700 | 450 | 6·71 |
| | 5 | 6 | 579 | 0·40 | 600 | 3892 | 649 | 28·8 | 2600 | 433 | 6·68 |
| | 6 | 6 | 576 | 0·30 | 600 | 3590 | 598 | 26·6 | 2400 | 400 | 6·69 |
| | Averages | 6 | 586 | 0·38 | 617 | 3835 | 639 | 28·4 | 2567 | 428 | 6·69 |

Height of boiler above firegrate 2 ft. 9 ins. Area of Firegrate 22½ square feet. Thickness of Fire at front of grate 10 inches.

## TABLE III.

*Experiments at Seaham Colliery, with Stanley's Mechanical Furnace (Plates 40 and 41).*

*No. 2 Boiler, plain cylindrical, with flash flue.*

| Description of Coal. | No. of Expt. | Duration of Expt. | Engine Strokes per hour. | Thickness of Fire at front of grate. | Water Gauge in Chimney. | Pyrometer in Flue. | Coal consumed. | | | Water evaporated. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total. | Per hour. | Per sq. ft. of grate per hour. | Total. | Per hour. | Per lb. of coal. |
| | No. | Hours. | | Inches. | Inch. | Fahr. | Lbs. | Lbs. | Lbs. | Gall. | Gall. | Lbs. |
| "Duff" (dust) | 1 | 6 | 550 | 8 | 0·45 | 685 | 5626 | 938 | 41·7 | 2250 | 375 | 4·00 |
| "Peas" (screened small) | 2 | 6 | ... | 9 | 0·45 | ... | 6264 | 1044 | 46·4 | 2550 | 425 | 4·07 |
| | 3 | 6 | 546 | 8 | 0·40 | ... | 5034 | 839 | 37·3 | 2300 | 383 | 4·57 |
| | 4 | 6 | 605 | 8 | 0·45 | 650 | 5072 | 845 | 37·6 | 2500 | 417 | 4·93 |
| | 5 | 6 | 536 | 8 | 0·50 | ... | 5094 | 849 | 37·7 | 2500 | 417 | 4·91 |
| | 6 | 6 | ... | 8 | 0·35 | ... | 5450 | 908 | 40·4 | 2600 | 433 | 4·77 |
| | 7 | 6 | 558 | 8 | 0·40 | ... | 5165 | 861 | 38·3 | 2700 | 450 | 5·23 |
| | Averages | 6 | 561 | 8 | 0·42 | ... | 5346 | 891 | 39·6 | 2525 | 421 | 4·74 |

Height of boiler above firegrate 2 ft. 7 ins. Area of Firegrate 22½ square feet.

## TABLE IV.

*Experiments at Seaham Colliery, with Vicars' Mechanical Furnace (Plates 42 and 43).*

*No. 3 Boiler, plain cylindrical, with flash flue.*

| Description of Coal. | No. of Expt. | Duration of Expt. | Engine Strokes per hour. | Thickness of Fire at front of grate. | Water Gauge in Chimney. | Pyrometer in Flue. | Coal consumed. | | | Water evaporated. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total. | Per hour. | Per sq. ft. of grate per hour. | Total. | Per hour. | Per lb. of coal. |
| | No. | Hours. | | Inches. | Inch. | Fahr. | Lbs. | Lbs. | Lbs. | Gall. | Gall. | Lbs. |
| "Peas" (screened small) | 1 | 6 | 494 | 13 | 0·40 | ... | 2981 | 497 | 25·5 | 1900 | 317 | 6·37 |
| | 2 | 6 | 588 | 13 | 0·42 | ... | 2744 | 457 | 23·4 | 2000 | 333 | 7·29 |
| | 3 | 6 | 459 | 15 | 0·40 | ... | 2740 | 457 | 23·4 | 1800 | 300 | 6·57 |
| | 4 | 6 | 553 | 15 | 0·40 | ... | 2632 | 439 | 22·5 | 2100 | 350 | 7·98 |
| | 5 | 6 | 657 | 15 | 0·40 | 400 | 2788 | 465 | 23·9 | 1900 | 317 | 6·81 |
| | 6 | 6 | 618 | 15 | 0·40 | 425 | 2731 | 455 | 23·3 | 1850 | 308 | 6·77 |
| | 7 | 6 | 592 | 15 | 0·45 | 550 | 2753 | 459 | 23·5 | 1870 | 312 | 6·79 |
| | 8 | 6 | 639 | 15 | 0·40 | 550 | 2495 | 416 | 21·3 | 1700 | 283 | 6·81 |
| | 9 | 6 | 608 | 15 | 0·35 | 500 | 2587 | 431 | 22·1 | 1900 | 317 | 7·34 |
| | 10 | 6 | 554 | 15 | 0·40 | ... | 2389 | 398 | 20·4 | 2100 | 350 | 8·79 |
| | Averages | 6 | 576 | 15 | 0·40 | 485 | 2684 | 447 | 22·9 | 1912 | 319 | 7·15 |
| "Duff" (dust) | 11 | 6 | 604 | 12 | 0·42 | ... | 2714 | 452 | 23·2 | 2000 | 333 | 7·37 |
| | 12 | 6 | 621 | 15 | 0·40 | ... | 2824 | 471 | 24·2 | 1800 | 300 | 6·37 |
| | 13 | 6 | ... | 15 | 0·40 | ... | 2288 | 381 | 19·5 | 1700 | 283 | 7·43 |
| | 14 | 6 | 522 | 15 | 0·40 | ... | 2415 | 402 | 20·6 | 1700 | 283 | 7·04 |
| | 15 | 6 | 630 | 15 | 0·37 | 500 | 2604 | 434 | 22·3 | 1600 | 267 | 6·11 |
| | 16 | 6 | 565 | 15 | 0·40 | 450 | 1947 | 324 | 16·6 | 1500 | 250 | 7·70 |
| | 17 | 6 | 626 | 15 | 0·40 | 525 | 2559 | 426 | 21·9 | 1650 | 275 | 6·45 |
| | 18 | 6 | 646 | 15 | 0·40 | 525 | 2664 | 444 | 22·8 | 1670 | 278 | 6·27 |
| | 19 | 6 | 646 | 15 | 0·37 | 525 | 2678 | 446 | 22·9 | 1670 | 278 | 6·24 |
| | 20 | 6 | 597 | 15 | 0·40 | 470 | 2560 | 427 | 21·9 | 1700 | 283 | 6·64 |
| | 21 | 6 | 639 | 15 | 0·37 | 500 | 2171 | 362 | 18·6 | 1650 | 275 | 7·60 |
| | Averages | 6 | 610 | 15 | 0·40 | 499 | 2493 | 415 | 21·3 | 1695 | 282 | 6·84 |

Height of boiler above firegrate 2 feet. Area of Firegrate 19½ square feet.

In Nos. 16 and 21 experiments the firebars were driven at their minimum speed; and in No. 19 at their maximum speed.

In No. 9 experiment there was a short stoppage owing to the breaking of the driving belt.

## TABLE V.

*Experiments at Seaham Colliery, with Juckes' Mechanical Furnace (Plates 37 to 39).*

*No. 4 Boiler, plain cylindrical, with flush flue. "Peas" (screened small) Coal.*

| No. of Experiment. | Duration of Expt. | Engine Strokes per hour. | Speed of Firebars. Ft. per hour. | Thickness of Fire at front of grate. | Water Gauge in Chimney. | Pyrometer in Flue. | Coal consumed. | | | Water evaporated. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Total. | Per hour. | Per sq. ft. of grate per hour. | Total. | Per hour. | Per lb. of coal. |
| No. | Hours. | | Feet. | Inches. | Inch. | Fahr. | Lbs. | Lbs. | Lbs. | Gall. | Gall. | Lbs. |
| 1 | 6 | 541 | 9 | 5 | 0·40 | ... | 3586 | 598 | 20·4 | 2200 | 367 | 6·13 |
| 2 | 6 | 612 | 9 | 5 | ... | 665 | 3806 | 634 | 21·7 | 2400 | 400 | 6·31 |
| 3 | 6 | 654 | 9 | 5 | ... | 650 | 3870 | 645 | 22·1 | 2400 | 400 | 6·20 |
| 4 | 6 | 672 | 9 | 5 | 0·45 | 770 | 3536 | 589 | 20·1 | 2200 | 367 | 6·22 |
| 5 | 6 | 661 | 9 | 5 | ... | 725 | 3381 | 563 | 19·2 | 2100 | 350 | 6·21 |
| 6 | 6 | 586 | 9 | 5 | 0·40 | ... | 4161 | 693 | 23·7 | 2200 | 367 | 5·29 |
| 7 | 6 | 473 | 9 | 5 | 0·37 | ... | 4004 | 667 | 22·8 | 2100 | 350 | 5·24 |
| 8 | 6 | 425 | 9 | 5 | 0·37 | ... | 4095 | 682 | 23·3 | 2300 | 383 | 5·62 |
| 9 | 6 | 547 | 8½ | 4½ | 0·40 | ... | 4236 | 706 | 24·1 | 2500 | 417 | 5·90 |
| 10 | 6 | 548 | 9 | 5 | 0·42 | ... | 4086 | 681 | 23·3 | 2400 | 400 | 5·87 |
| Averages | 6 | 572 | 9 | 5 | 0·40 | 702 | 3876 | 646 | 22·1 | 2280 | 380 | 5·90 |

No side waterboxes. Height of boiler above firegrate 1 ft. 7 ins. Area of Firegrate 29¼ square feet.

## TABLE VI.

*Experiments at Silksworth Colliery.*

*Single Tubular Boiler (Cornish) fired in Tube by Hand (Fig. 5, Plate 36.) "Peas" (screened small) Coal.*

| Description of Flue. | No. of Experiment. | Duration of Experiment. | Water Gauge in Chimney. | Coal consumed. | | | Water evaporated. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Total. | Per hour. | Per sq. ft. of grate per hour. | Total. | Per hour. | Per lb. of coal. |
| | No. | Hours. | Inch. | Lbs. | Lbs. | Lbs. | Gall. | Gall. | Lbs. |
| | 1 | 6 | ... | 1344 | 224 | 18·1 | 680 | 113 | 5·06 |
| Flash Flue. | 2 | 6 | ... | 1456 | 243 | 19·6 | 750 | 125 | 5·15 |
| Draught taken | 3 | 6 | ... | 1456 | 243 | 19·6 | 670 | 112 | 4·60 |
| direct from Tube | 4 | 6 | ... | 1120 | 187 | 15·1 | 555 | 92 | 4·96 |
| to chimney. | 5 | 6 | ... | 1008 | 168 | 13·6 | 495 | 82 | 4·91 |
| | 6 | 6 | ... | 1176 | 196 | 15·8 | 550 | 92 | 4·68 |
| | 7 | 6 | ... | 1120 | 187 | 15·1 | 530 | 88 | 4·73 |
| | Averages | 6 | 0·08 | 1240 | 207 | 16·7 | 604 | 101 | 4·87 |
| | 8 | 6 | ... | 1120 | 187 | 15·1 | 580 | 97 | 5·18 |
| | 9 | 6 | ... | 1120 | 187 | 15·1 | 590 | 98 | 5·27 |
| Wheel Flue. | 10 | 6 | ... | 1232 | 205 | 16·6 | 660 | 110 | 5·36 |
| Draught taken | 11 | 6 | ... | 1008 | 168 | 13·6 | 570 | 95 | 5·65 |
| all round boiler. | 12 | 6 | ... | 1008 | 168 | 13·6 | 575 | 95 | 5·70 |
| | 13 | 6 | ... | 1008 | 168 | 13·6 | 575 | 95 | 5·70 |
| | 14 | 6 | ... | 1120 | 187 | 15·1 | 640 | 107 | 5·71 |
| | Averages | 6 | 0·08 | 1088 | 181 | 14·7 | 599 | 100 | 5·51 |

Diameter of Boiler Tube 2 ft. 6 ins. Height from firegrate to top of Tube 1 ft. 3 ins.
Area of Firegrate $12\frac{3}{8}$ square feet. Thickness of Fire at front of grate 6 inches.

## TABLE VII.

*Experiments at Silksworth Colliery.*

*Single Tubular Boiler fired underneath by Hand (Fig. 5, Plate 36.) "Peas" (screened small) Coal.*

| Description of Flue. | No. of Experiment. | Duration of Experiment. | Water Gauge in Chimney. | Coal consumed. | | | Water evaporated. | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Total. | Per hour. | Per sq. ft. of grate per hour. | Total. | Per hour. | Per lb. of coal. |
| | No. | Hours. | Inch. | Lbs. | Lbs. | Lbs. | Gall. | Gall. | Lbs. |
| | 1 | 6 | ... | 2688 | 448 | 18·9 | 1240 | 207 | 4·61 |
| Flash Flue. | 2 | 6 | ... | 2912 | 485 | 20·4 | 1505 | 251 | 5·17 |
| Draught taken | 3 | 6 | ... | 2800 | 467 | 19·7 | 1523 | 254 | 5·44 |
| | 4 | 6 | ... | 2688 | 448 | 18·9 | 1400 | 233 | 5·21 |
| direct to chimney. | 5 | 6 | ... | 2576 | 429 | 18·1 | 1200 | 200 | 4·66 |
| | 6 | 6 | ... | 2576 | 429 | 18·1 | 1200 | 200 | 4·66 |
| | Averages | 6 | 0·08 | 2707 | 451 | 19·0 | 1345 | 224 | 4·96 |
| | 7 | 6 | ... | 2632 | 439 | 18·5 | 1210 | 202 | 4·60 |
| | 8 | 6 | ... | 2576 | 429 | 18·1 | 1235 | 206 | 4·79 |
| Wheel Flue. | 9 | 6 | ... | 2576 | 429 | 18·1 | 1220 | 203 | 4·74 |
| Return Draught | 10 | 6 | ... | 2464 | 411 | 17·3 | 1200 | 200 | 4·87 |
| through Tube, and back by | 11 | 6 | ... | 2744 | 457 | 19·2 | 1290 | 215 | 4·70 |
| double side flues. | 12 | 6 | ... | 2800 | 467 | 19·7 | 1300 | 217 | 4·64 |
| | Averages | 6 | 0·08 | 2632 | 439 | 18·5 | 1243 | 207 | 4·72 |

Height of boiler above firegrate 2 ft. 10 ins. Area of Firegrate 23¾ square feet. Thickness of Fire at front of grate 12 inches.

# TABLE VIII.

## MECHANICAL FIRING OF STEAM BOILERS.

*Abstract of Average Results of Experiments.*

| Mode of Firing. | Boiler. Description. | Total Length. | Diameter. | Height above firegrate. | Pressure of Steam. | Description of Covering. | Description of Flue. | Area of Firegrate. | Thickness of Fire at front of grate. | Description of Coal. | Water Gauge in Chimney. | Pyrometer in Flue. | Coal consumed. Per hour. | Coal consumed. Per sq. ft. of grate per hour. | Water evaporated. Per hour. | Water evaporated. Per lb. of coal. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Table I. | | Ft. | Ft. | Ft. Ins. | Lbs. | | | Sq. Ft. | Inches. | * | Inch. | Fahr. | Lbs. | Lbs. | Gall. | Lbs. |
| JUCKES, *without* waterboxes | Plain Cylindrical egg-ended. | 37 | 6 | 2 0 | 30 | Composition | Flash | 24 | 3½ to 4 | Peas | ... | ... | 521 | 21·7 | 243 | 4·69 |
| Do. *with* do. | | 37 | 6 | 1 6 | 30 | Not covered | Flash | 24 | 3½ to 4 | Peas | 0·32 | ... | 517 | 21·5 | 249 | 4·84 |
| Do. *with* do. | | 37 | 6 | 1 6 | 30 | Composition | Flash | 24 | 3½ to 4 | Peas | 0·30 | ... | 511 | 21·3 | 256 | 5·02 |
| Do. *with* do. | | 37 | 6 | 2 0 | 30 | Composition | Flash | 24 | 3½ to 4 | Peas | 0·30 | ... | 502 | 20·9 | 267 | 5·33 |
| Table V. Do. *without* do. | Do. | 33 | 7½ | 1 7 | 12 | Shed | Flash | 29¼ | 5 | Peas | 0·40 | 702 | 646 | 22·1 | 380 | 5·90 |
| Table III. STANLEY | Do. | 33 | 7½ | 2 7 | 12 | Shed | Flash | 22½ | 8 | Peas | 0·42 | 650 | 891 | 39·6 | 421 | 4·74 |
| Table IV. VICARS | Do. | 33 | 7½ | 2 0 | 12 | Shed | Flash | 19½ | 15 | Peas | 0·40 | 485 | 447 | 22·9 | 319 | 7·15 |
| | | | | | | | | | 15 | Duff | 0·40 | 499 | 415 | 21·3 | 282 | 6·84 |
| Table II. HANDFIRING | Do. | 33 | 7½ | 2 9 | 12 | Shed | Wheel | 22½ | 10 | Peas | 0·42 | ... | 574 | 25·5 | 289 | 5·03 |
| | | | | | | | Flash | 22½ | 10 | Peas | 0·38 | 617 | 639 | 28·4 | 428 | 6·69 |
| Table VI. HANDFIRING in Tube. | Single Tubular. Tube 2 ft. 6 ins. diam. | 30 | 6 | 1 3 | 30 | Not covered | Flash | 12⅜ | 6 | Peas | 0·08 | ... | 207 | 16·7 | 101 | 4·87 |
| | | | | | | | Wheel | 12⅜ | 6 | Peas | 0·08 | ... | 181 | 14·7 | 100 | 5·51 |
| Table VII. HANDFIRING below Boiler. | | 30 | 6 | 2 10 | 30 | Not covered | Flash | 23¾ | 12 | Peas | 0·08 | ... | 451 | 19·0 | 224 | 4·96 |
| | | | | | | | Wheel | 23¾ | 12 | Peas | 0·08 | ... | 439 | 18·5 | 207 | 4·72 |

* "Peas" coal, screened small coal or slack about the size of peas. "Duff," the dust coal from the screening of the "peas."

Mr. T. Hawksley observed that the evaporative duty obtained in the experiments described in the paper appeared to him very low, even allowing for the small size of the coal used, the economic effect being less than 5 lbs. of water per lb. of coal; and he thought there must have been some disadvantageous circumstances in connection with the boilers experimented upon, that would interfere with the correctness of comparisons between the different modes of mechanical firing which had been tried. The worst coal that he knew of, which was used for the purpose of generating steam, evaporated in a common boiler very nearly 7 lbs. of water per lb. of coal, when used in the form of large coal; and the best Welsh steam coal evaporated as much as 11 or $11\frac{1}{2}$ lbs. of water per lb. of coal. The Juckes mechanical furnace having recently been applied for firing four large boilers which he was acquainted with at the Stockton and Middlesbrough Water Works, it had been found that practically there was no difference whatever in the evaporative duty obtained from the same coal before and after the application of the apparatus. The generation of steam indeed was not quite so rapid with the mechanical firing as in hand-firing; but the great advantage of the mechanical firing was that it considerably diminished the quantity of smoke evolved. This was likely he thought to be the principal advantage of any apparatus for mechanical firing; and it was one which was of particular importance in large towns, where the prevention of smoke was so very desirable. Any of the plans of mechanical firing described in the paper would he believed accomplish this object equally well, but not without requiring probably for the purpose a much larger area of firegrate surface than was commonly allowed in the firing of steam boilers. The Stanley apparatus he had known in use for thirty years, and believed no better contrivance had been devised for mechanical firing; but except in respect of preventing smoke he did not think mechanical appliances possessed any practical superiority over careful hand-firing. With regard to the setting of boilers, very little value appeared to be attributed in the paper to the wheel draught, of which the usual arrangement consisted in firing the boiler internally in a tube, and then bringing the draught back under the bottom of the boiler to the front end,

and forwards again by two side flues to the chimney, so as to take the heat completely round the boiler before letting it escape to the chimney. If the wheel flue were really of very little use, he thought it could only be because nearly the whole of the work of evaporation was done in the furnace itself or within a very short space beyond it; but although it was quite true that the rate of evaporation was much greater immediately over the furnace and in a short length of the tube beyond, yet it had been found by practical experience that in an ordinary wheel flue of average length 3 square feet of external flue surface would do about the same work in evaporation as 1 square foot of surface in the internal tube beyond the fire.

Mr. Daglish observed that the opinion just expressed as to the comparative value of mechanical firing and hand-firing agreed with the conclusion arrived at from the experiments described in the paper, which showed that with the Juckes furnace there was no advantage in economy of fuel over hand-firing, when the latter was done with great care. The maximum evaporative duty of any particular description of coal did not affect the results of the experiments, as the question was the relative duty obtained from the same description of fuel by the two modes of firing, other circumstances being the same. The coal used in the experiments described in the paper was entirely refuse coal of very small size, no larger than peas; and the boilers fired with it were the ordinary boilers used at the collieries in that district, which were less expensive both in first cost and maintenance than the better class of boilers that were fired with large coal; and it was only when the fuel employed was entirely large coal that the higher evaporative duty was obtained which had been mentioned. Even with one of these boilers that was not provided with any covering whatever, the economic effect of the "peas" coal fired by a Juckes furnace was not lower than 4·84 lbs. of water per lb. of coal; and with the same description of coal and the same mode of firing, a result as high as 5·90 lbs. of water had also been obtained with a larger firegrate, and with very careful hand-firing even 6·69 lbs. of water per lb. of coal. These results he thought could not be regarded as otherwise than highly favourable to the refuse small coal of the district for

the firing of steam boilers. There were some anomalous results in the experiments described in the paper, and this was particularly the case in regard to the Stanley furnace, in which the economic effect had ranged from 4 to $5\frac{1}{4}$ lbs. of water per lb. of coal; but a number of careful experiments would be required to find what was the best speed of the dispersers and the best thickness of fire for obtaining the maximum effect from this mode of firing. In reference to the wheel draught for boiler furnaces, this arrangement was at one time almost universally employed in that district, but it was now generally abandoned in favour of the flash flue, thereby confirming the conclusions arrived at from the experiments in the paper. In the ordinary wheel-flue arrangement there was less boiler surface exposed to the direct action of the fire than with a flash flue; and when the wheel flue was converted into a flash flue, the diminution in the length of boiler surface to be traversed by the heat was fully made up by the larger extent of surface exposed directly to the heat in the immediate neighbourhood of the fire. The pyrometer observations in the flue beyond the boiler showed that the waste heat passing off from the flash flue was rarely above 700° Fahr., and at that temperature the current of heated air did not part rapidly with its heat, so that very little advantage would be derived from any further extent of boiler surface in the flue.

Mr. T. Hawksley remarked that in experiments which he had made to determine the relative value of small coal, such as that described in the paper as "peas" coal, and the same quality of coal in the state of large coal, he had found the economic effect of the two to be about in the ratio of 6 to 7; so that practically there was not any great difference between the two sorts. This was the case, provided that the small coal was cleaned, and that the chimney was high enough to draw a sufficient quantity of air through the small coal for ensuring its being effectively consumed: but in the absence of these conditions there was a considerable loss of economic effect in the use of the small coal. In the experiments that he had made, the chimney was 100 feet high, giving a draught equal to $\frac{5}{8}$ inch column of water, and in the ordinary working of the boilers with

large coal the draught was reduced by the damper to about $\frac{1}{4}$ inch of water; but the small coal, having much smaller spaces left for the passage of the air, offered a considerable resistance to the entrance of air through the fuel itself, and required a draught of $\frac{1}{2}$ inch or even the full draught of $\frac{5}{8}$ inch for producing efficient combustion. When the two sorts of coal were thus burnt under circumstances that were suitable to their different characters, he had found that an evaporative duty might be obtained from the small coal nearly but not quite as good as from the large.

The PRESIDENT enquired what was the height of the chimney in the experiments described in the paper.

Mr. DAGLISH replied that the chimney was 70 feet high in the experiments at Seaham.

Mr. T. R. CRAMPTON observed that with the long boilers which were in general use in that district it was certainly very likely there would be no advantage in return flues, and that the single straight flue would be sufficient for absorbing the heat to such an extent that not more than 300° or 400° Fahr. of waste heat should escape into the chimney. But he did not think that on this account it was practicable to lay down any general rule respecting the adoption of the wheel flue or the flash flue: the economy attending either of these arrangements would depend upon the length of the boiler, the force of the chimney draught, and the description of fuel employed. In order to provide for evaporating economically any given quantity of water per hour, it was necessary that the rate of combustion of the fuel, the extent of boiler surface exposed to the heat, and the area of the flues, should be properly proportioned to one another; and in boilers where the heat was sufficiently absorbed during its passage along the length of a straight flash flue, the addition of return flues would be objectionable. The experiments described in the paper having all been made with the common refuse coal of the district, the actual evaporative duty was of course lower than it would have been if the lump coal from the same seams had been used; but this did not affect the value of the results obtained, as the object of the experiments was not to compare the economic effects of different descriptions of coal in different districts, but

with the cheapest fuel that was used for firing steam boilers in the North of England to ascertain the relative value of hand-firing and of various mechanical contrivances for the purpose. This object he thought had been satisfactorily accomplished by the experiments described, the same quality of refuse small coal being employed throughout; and the conclusion arrived at appeared to be that in respect of economy of fuel there was not much difference between mechanical firing and careful hand-firing.

A very important question to be considered however, in regard to the utilisation of refuse small coal, was the means whereby its economic effect could be raised more nearly to an equality with that of the same fuel in the state of large coal; because theoretically the evaporative duty to be obtained from any particular sort of coal was of course the same, whatever the condition in which it existed, whether as lump coal or as slack. The practical difference in value between the same coal in different states arose he considered from the fact, that in the use of large coal the interstices left between the lumps for the passage of the air were large enough to admit sufficient air for a more efficient combustion of the coal; but in burning small coal it was not possible to get air enough to pass through it in an ordinary firegrate for developing all the heat which the complete combustion of the fuel should yield. The most perfect mode of employing any sort of fuel was in the form of gas or oil, in which states there were the greatest facilities for supplying it with the exact theoretical proportion of air required for producing the maximum development of heat. But in default of the use of gas or oil, the nearest approach to the gaseous or liquid state was that of very fine coal dust; and he was at the present time engaged in experiments for the purpose of maturing a method by which the fuel might be consumed in the form of a fine powder, with an admixture of the proper quantity of air for ensuring complete combustion. The coal was ground to powder, and was then blown in a cloud of fine dust into a combustion chamber by a blast of air, which was proportioned to the quantity and quality of the coal dust; and as the mixture of the dust and the air was so intimate, it was not necessary in this arrangement to supply a large excess of

air in order to make sure of burning the coal. Even in the use of gas however, a certain minute period of time was required for the gas to become completely mixed with the air; and a somewhat longer period was necessary for the same purpose in the case of solid fuel in the form of powder, because the solid particles had to be converted into a gaseous state before they could combine with the air; consequently the length of time required for this process increased with the size of the particles of coal dust. The combustion chamber therefore, in which the mixture of dust and air was ignited, was constructed so as to form a long zig-zag or circuitous passage for detaining the mixture of coal dust and air long enough for the whole of the solid particles of coal to become completely volatilised and combined with the air. The coal dust being blown into this chamber, its tortuous course ensured the complete admixture of the air and the thorough combustion of the carbon. At the same time the impurities contained in the coal dust were deposited on the brick surfaces, forming a slag which trickled down to the bottom and was tapped out at intervals; while a clean flame, free from dirt and of maximum heating power, was delivered into the heating chamber in which the heat was desired to be made use of. In trials which he had made of West Hartley coal consumed in this manner in a locomotive boiler, he had found that with a given size of particles the duty obtained was $9\frac{1}{4}$ lbs. of water evaporated per lb. of coal, while the products of combustion passing off through the boiler tubes contained from 12 to 13 per cent. of unconsumed carbon carried away as waste; but by using a little finer powder the same coal gave an evaporative duty of 10 to 11 lbs. of water, with proportionately less waste in the form of unconsumed carbon. This proved that it was practicable to obtain actually a greater heating effect from small coal than from large coal, when suitable arrangements were made for providing the small coal with the required proportion of air for its complete combustion.

A practical trial of this plan of burning coal had been in operation at the Longhedge Works, Battersea, upon one of a pair of reverberatory furnaces, which were previously both worked exactly alike; one of these had been altered for the trial by taking out

the firegrate, and putting in a combustion chamber with a series of compartments, at the end of which the coal dust was blown in, while the flame from the top passed over the bridge into the reverberatory chamber of the furnace, in the same way as in the other ordinary furnace, but free from the impurities attending the use of the ordinary firegrate. The dust coal used for the firing cost altogether about 14*s.* per ton, and the grinding about 14*d.* per ton in addition, making about 15*s.* 2*d.* per ton as the total cost of the fuel. The furnace being charged with scrap consisting of thick tyre bars, it was found that the heats of 9 cwts. were turned out in 28 to 33 minutes, the average of the day's work being 30 minutes per heat. This was certainly a very remarkable result; and the same quantity of work that ordinarily occupied 12 hours was now got through in the new furnace in $5\frac{1}{2}$ hours by the same men. The quantity of coal dust used was $19\frac{1}{2}$ cwts., as compared with 30 cwts. of large coal in the ordinary furnace for the same work done. The reason of this saving of fuel he considered could only be found in the excess of air which it was necessary to admit with an ordinary firegrate, in order to make sure of supplying air enough for the combustion of the coal; and in an ordinary reverberatory furnace it would appear that in this way a large excess of air, nearly equal probably to the quantity actually required by the fuel, passed through the furnace without being consumed, having the effect of lowering the temperature of the furnace and injuring the iron by the great excess of free oxygen passing through the furnace. By this plan of blowing dust coal in and proportioning the admission of air to the quantity of fuel used, he had succeeded in reducing the excess of air to not more than about 20 per cent. beyond the theoretical quantity required for the fuel; and this he thought was sufficient to account for the result attained with the new furnace of turning out the same quantity of work in less than half the time of the ordinary furnace. On examining the several compartments of the combustion chamber in the new furnace after the completion of an extensive series of experiments, it was found that the surface of the brickwork was entirely free from deposit at the bridge of the furnace and in the uppermost compartment, showing that the gas

flame passing over the bridge into the reverberatory chamber was entirely free from impurities or dirt of any description; whilst in the lower parts of the combustion chamber the deposit of slag upon the walls gradually increased, and hung in drops from the walls. The new furnace was thus practically a gas furnace, and had all the advantage of a gas furnace in supplying the required heat without any risk of injuring the work in the furnace by the presence of impurities or solid particles of carbon carried over in the flame; and in consequence also of the very complete combustion of the fuel, no smoke whatever was produced in this mode of firing.

Mr. I. Lowthian Bell observed that there could be no question the theoretical amount of heat to be obtained from any coal was independent of its size, provided that the different sizes of coal were of equally good quality, containing equal proportions of the earthy ingredients which formed the ash when the coal was burnt. This however was by no means the case, as there was a very great extent of variation in the difference between lump coal of any description and the same coal in the state of small. The breaking up of the solid coal in the process of getting allowed the earthy matter contained in the cleavages of the seam to fall out; this all became mixed with the smaller fragments of pure coal, forming the refuse small coal that had been used in the experiments described in the paper. The proportion of ash in the large coal was thus diminished, and that in the small coal increased; and the extent of the difference depended upon the particular quality of each individual seam. At one of the collieries with which he was connected in that district the seam of coal worked was of such uniform quality that the small coal did not contain $\frac{1}{2}$ per cent. more refuse matter than the large coal; whereas at other collieries in the same district the proportion of refuse matter in the large coal was only from 5 to 6 per cent., while in the small coal it was as much as 16 per cent.; and having examined the small coal used in the experiments described in the paper he had found it contained as much as 18 to 20 per cent. of ash. This difference between large and small coal was therefore required to be taken into consideration in relation to the lower evaporative duty obtained from the small coal used in those experiments.

With regard to the relative advantages of a wheel flue or a flash flue, he thought the point to be considered was the length of time during which the furnace heat was in contact with the boiler surface; and so long as this time was kept the same, the shorter flue with the draught taken off direct to the chimney would give as good results as the longer flue passing back round the boiler. The extent of boiler surface exposed to the heat was indeed pretty much the same in the straight flash flue as in the wheel flue, because the absence in the flash flue of the partition walls upon which the boiler was set in the wheel-flue arrangement left an increased area of surface exposed to the heat. In the ordinary long cylindrical boilers employed at the collieries in that district he believed the actual proportion of heating surface with a flash flue was about as 9 to 10 in comparison with that afforded by a wheel flue.

The PRESIDENT considered they were much indebted to the author of the paper for the results which he had communicated of the valuable series of experiments upon the different modes of mechanical firing. The adoption of mechanical appliances for this purpose was an important subject for consideration, and their use was more prevalent in that district probably than in any other; and the Members would have the opportunity of seeing the various arrangements in practical operation at different works in the neighbourhood. At the Elswick Works mechanical methods were now very extensively applied for firing the steam boilers, the arrangement employed for the purpose being the Vicars furnace. The first application of this furnace was without the arrangement of water troughs for cooling the firebars, and was not found satisfactory in consequence of the speedy destruction of the bars; but after a number of experiments, resulting in the addition of the water troughs, the furnace had proved much more successful, and he had no doubt that eventually it would realise the object of entirely superseding hand-firing for steam boilers. The experience at the Elswick Works as to the evaporative duty of the fuel was that this was much about the same with the mechanical furnace as in hand-firing; but the same boilers would produce more steam, with a proportionate consumption of fuel, by mechanical firing than by

hand-firing. Mechanical firing also had the decided advantage of entirely preventing smoke, which was alone a sufficient argument in its favour. The production of smoke from steam engine fires he was satisfied could be completely prevented by skilful hand-firing; but the difficulty was to get the amount of constant care and skill that was required to be bestowed upon hand-firing for this purpose. In one instance that he knew of, the plan adopted had been simply to discharge the fireman if any smoke was produced; but this was not a policy that could be conveniently followed. Apart from steam boilers there were certainly some other kinds of furnaces, from which, in the present state of experience of their working, it seemed impracticable to prevent smoke being produced; but by far the greater quantity of the smoke which disfigured so many towns proceeded from steam boiler fires, and in those cases, with the means now at command for mechanical firing, he was satisfied there was no excuse whatever for the production of smoke.

The remarks were of much interest that had been made in the discussion respecting the combustion of the coal under conditions analogous to those attending the burning of gas, by employing it in the state of a fine dust mixed with atmospheric air in the proper proportion for effecting its complete combustion; and from a theoretical point of view this plan certainly appeared to be very promising. In all novel applications of that kind however, the ultimate result depended greatly upon practical considerations; and he hoped the trial which was being made would satisfactorily establish the practicability of employing fuel successfully in that manner.

He proposed a vote of thanks to Mr. Daglish for his paper and the accompanying valuable tables of experiments, which was passed.

The Meeting was then adjourned to the following day. In the afternoon Excursions were made by the Members in three parties to Seaton Delaval Colliery and Ryhope Colliery, and on board a new large Steamer, the "Duchess of Sutherland," off Tynemouth; and the Members received a hospitable entertainment from Mr. Thomas E. Forster at Seaton Delaval, from the Owners of the Colliery at Ryhope, and from Messrs. Robert Stephenson and Co. on the Steamer.

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In the evening the following Address was delivered in the Lecture Theatre by the President, Sir William G. Armstrong:—

# ADDRESS OF THE PRESIDENT.

This year is the centenary of the Steam Engine of Watt; and I am glad that it has fallen to the lot of Newcastle-upon-Tyne to receive on so auspicious an occasion a Society which must regard Watt, more than any other man, as the father of their calling. First then I shall discharge my duty as your President, by paying a tribute of respect to the memory of the illustrious man, who in the corresponding year of the last century completed and set to work the greatest of mechanical inventions.

In 1765 the authorities of Glasgow College, little thinking of the momentous step they were taking, entrusted a model of a Newcomen engine to James Watt, a maker of mathematical instruments, for repair. The sagacity of Watt enabled him by an inspection of the model to detect a radical defect in the principle of the engine. He saw that the condensation effected within the cylinder reduced its temperature, and rendered restoration of the wasted heat necessary at every stroke. He perceived that the steam ought to act in a vessel always hot, and be condensed in a vessel always cold. He thus conceived the idea of separate condensation. With a quiet tenacity of purpose he set to work under great disadvantages to realise his idea of a more economical steam engine. His design was soon matured, but the difficulty of execution long remained a barrier to practical success. In the Newcomen engine the weight of the atmosphere acting against a vacuum was the moving power, and leakage of air past the piston was prevented by water resting on the upper side. An unbored cylinder, made in separate parts, sufficed for this arrangement; but in Watt's design, steam instead of air acted on the piston; a water packing was inapplicable; and leakage

could only be prevented by the more accurate fit of the piston in the cylinder. A moderately steam-tight cylinder and piston were however more than the workshops of the day could produce; and we read of his vain attempts to correct, by pasteboard and cork, inaccuracies of workmanship such as in our time have no existence. With ailing health, narrow pecuniary means, and a temperament inclining to despondency, he was in many respects unfitted for a struggle with difficulty; but he was a man whose mind was taken captive by an idea, and he could not help persevering. His attractive character and fine intellect had attached to him many valuable friends, superior in station to himself; and his letters to some of those friends, written during his struggles, exhibit at once his severe discouragement and his irresistible impulse to proceed. In 1768 he had succeeded in producing a condenser with its necessary appendage of an air-pump, but it was not until the following year 1769—exactly a century ago—that his first complete steam engine was finished and put in motion. The first trial was made by Watt in a secluded glen behind the house of his friend, Dr. Roebuck, near Linlithgow. The engine was not a mere working model, but a machine of considerable power. It had a cylinder of 18 inches diameter, and a stroke of 5 feet; but the cylinder and piston, which were described as the best the Carron Iron Works could produce, were still so inaccurately made as to defeat in a great measure the anticipated success. The engine however afforded a practical demonstration of the value of the invention, sufficient to lead eventually to the happy alliance of the capital of Boulton with the genius of Watt. In 1773 the engine was removed to Mr. Boulton's works at Soho, and was fitted with a new cast-iron cylinder, the casting and boring of which were deemed no small achievements in those primitive days of mechanical engineering. This first engine of Watt was, like that of Newcomen, only applicable to pumping; but Watt quickly saw by what modifications it could be rendered available for rotative motion. By a succession of brilliant inventions, comprising amongst others his parallel motion and his ball governor, he advanced to the final conception of the double-acting rotative engine, which became applicable to every purpose requiring motive

power, and continues to this day in nearly its original form to be the chief moving agent employed by man.

To do full justice to the genius of Watt, we must consider the disadvantages under which he laboured. In the present day every contrivance is practicable in a constructive point of view; and the vast variety of devices used in modern mechanism, and applicable to new mechanical combinations, are made known to inventors in minute detail by the press. But Watt had no such facilities. He had to draw from his own mind what we can now choose from pre-accomplished invention, and his choice of means was restricted to the narrow limits of what was practicable in the rude workshops of the period. If we give due weight to these considerations, we shall be able to appreciate the remarkable originality of his mind, and the sagacity displayed in his inventions.

Watt lived to see his steam engine bear fruit in marvellous utility to the human race; but he could have had no idea of the results it was destined to realise before the expiration of the first century of its existence. It is impossible to contemplate these results without feelings of enthusiasm. To appreciate how much we owe to the steam engine, we need only consider for a moment what our position would be if we were deprived of its agency. The factories which clothe all the nations of the earth would be almost extinguished. The deep mines which supply nearly all our mineral wealth would be abandoned. The manufacture of iron would sink into comparative insignificance. Horses and sailing ships would again become our only means of transit. All great engineering works would cease, and mankind would relapse into that condition of slow and torpid progress, which preceded the subjugation of steam by Watt.

Having thus, in honour of an inventor whose name will grow greater as the world grows older, referred in general terms to engineering progress during the last hundred years, I need but glance at some of the more recent achievements in mechanical and constructive art, in order to show that the extraordinary advance of the century continues unabated. That such is the fact will at once be apparent, when I remind you that during the short period of

eleven years, which has elapsed since the Institution of Mechanical Engineers last held their annual meeting in this town, the Atlantic Telegraph Cables, the Suez Canal, and the great Railway across the American Continent, exceeding in length the sea passage from Europe to America, have been added to the engineering triumphs of the century. Of these there is but one of which England can claim the glory, and that is the first successful Atlantic Telegraph. The recondite science involved in that undertaking, the boldness of the enterprise, the perseverance displayed after the first failure, and the moral effects, as yet but partially developed, of its ultimate success, justify us in regarding the first Atlantic telegraph as one of the very greatest and most honourable achievements of man. But Englishmen may feel additional pride in reflecting that the successful laying of that cable, as well as of the subsequent French one just now completed, was chiefly due to the fact that there had been previously completed in this country a steam-ship of such gigantic size as to be itself one of the greatest wonders of modern engineering. Thus it is that one great invention hangs upon another. First came the steam engine, then followed the great steam-ship, and finally the Atlantic cable, which without the aid of steam could never have been laid.

The Suez Canal presents another example of the direct application of the steam engine to the execution of one of the most remarkable of modern works, the chief part of the canal having been executed by steam dredgers, of which an interesting description was received by this Institution at the Paris Meeting. In contemplating this undertaking, we are naturally led to compare it with the great neighbouring relics of Egyptian antiquity. In quantity of material moved, the Suez Canal is far more vast than the great Pyramid. In its moral and intellectual aspect, it is immeasurably superior. The ancient work is a useless monument of the idle vanity of a tyrant; the modern work will bear witness to the practical science and utilitarian spirit of our better times. Surely the world improves as the dominion of mind over matter is extended.

I should lengthen my observations too much if I were to review the many new and important applications of machinery and

mechanical processes, effected since our last meeting here. The manufacture of iron and steel—steam-cultivation—mining operations —steam locomotion, by land and water—economy of labour and of time—economy of fuel—printing—and even the humble business of the seamstress—have all been facilitated and promoted by recent mechanical progress.

The subject of Coal follows naturally a notice of the steam engine, and has a special interest for us in a locality celebrated, since the earliest days of coal mining, for the production of that invaluable mineral. England, with her innumerable steam engines and manufactories, is more dependent upon coal for the maintenance of her prosperity than any other nation; and the question of the duration of her coalfields now very properly occupies the attention of a Royal Commission. The investigations of that commission are not yet completed, but so far as they have gone the results are re-assuring. I concur in the probable accuracy of the announcement lately made by two of my fellow commissioners, that the total quantity of coal in this island will prove to be practically inexhaustible; but until the complicated details of quantities collected by the commission have been put together and expressed in totals, it is difficult to judge with certainty or accuracy on the subject. Although the duration of our coal may, geologically speaking, be practically unlimited, we have still to consider the important question, how long will England be supplied with coal as good and as cheap as at present. We have unquestionably made greater inroads into our best and most accessible coal beds than other nations have done into theirs; and if foreign coal should grow better and cheaper, and ours dearer and worse, the balance may turn against us as a manufacturing country long before our coal is exhausted in quantity. It is clear that our stock of good coal is very large, but most of it lies at great depths, and one of the most important questions the royal commission has to investigate is the depth at which coal can be worked with commercial advantage. The chief obstacle to reaching extreme depth is the increase of temperature which is met with as we descend. I am justified by ascertained facts in saying that this rate of increase will, as a rule, prove to be not less than 1° Fahrenheit for every 20 yards in depth,

and there is reason to expect that it will be even more rapid at greater depths than have yet been attained. The constant temperature of the earth in this climate at a depth of 50 feet is 50°; and the rate of increase as we descend is to be calculated from this starting point. Adopting these figures, we find that the temperature of the earth will be equal to blood heat at a depth of about 980 yards, and at a further depth of 500 yards mineral substances will be too hot for the naked skin to touch with impunity. It is extremely difficult to form an opinion as to the maximum temperature in which human labour is practicable in the damp atmosphere of a mine; and it is almost equally difficult to determine how much the temperature of the air in the distant parts of an extremely deep mine can be reduced below that of the strata with which it is brought in contact. It is certain however that the limit of practicable depth will chiefly depend upon the mechanical means which can be provided for relieving the miners of the severest part of their labour; for maintaining a supply of sufficiently cool air at the working faces of the coal; and for superseding the use of horses, which suffer even more than men from highly heated air. For the relief of labour we must look to coal-cutting machines; for improvement of ventilation to exhausting fans; and for the superseding of horses to hauling engines driven by transmitted power. The employment of coal-cutting machines, working by compressed air conveyed into the mine by pipes, is already an accomplished fact; and when the difficulties and objections, which usually adhere for a considerable time to new mechanical arrangements, are removed from these machines, they will probably attain extensive application. One of the earliest attempts at coal-cutting by machinery was described by the late Mr. Nicholas Wood at the former Newcastle Meeting of this Institution, and all the really practical results as yet obtained date from that period. The cooling influence of the expanding air as it escapes from these machines will be a collateral advantage of considerable importance in the hot atmosphere of a deep mine. The air discharged from the pneumatic coal-cutting machines now in use in the Hetton Colliery escapes into the mine at a temperature of 7° below freezing, and the cold air from each machine appears to be sufficient in quantity to

lower the temperature of the circulating atmosphere by 1°. If, as seems to be probable, six or seven of these machines can be employed at each working face, we may by this means lessen the heat by a corresponding number of degrees, and thus afford very considerable relief. The employment of compressed air as a motive power in substitution of horse traction is also quite feasible, and may be expected to become general in very deep workings. As regards ventilation, the fan machines of the several constructions tried have already exhibited great superiority over the old method of ventilating by an upcast furnace shaft; and although the efficiency of the furnace system of ventilation is increased by depth, there is reason to believe that the fan will maintain its superiority to greater depths than are likely to be reached in mining.

Thus far I have spoken of mechanical engineering as applied to purposes of production. I have now to refer to it as connected with the opposite element of destruction.

When battles were fought hand to hand, war, so far as mechanics are concerned, was an affair of muscular force, and was in that form the most sanguinary, because combats were the most close. When other forces were called into play, inventive appliances became necessary; and these, as they have advanced, have more and more widened the distances separating combatants, and have thus operated to prevent that greater sacrifice of life which would otherwise have resulted from the employment of more destructive weapons. It is therefore not to be supposed that future wars will be rendered more murderous by the intervention of the engineer. On the contrary, we may fairly anticipate that, the more the element of intelligence supersedes that of animal force in military struggles, the more will the barbarity of war be mitigated. Science naturally sides with civilisation, and tends to establish a supremacy over barbarism; and we find this tendency, as in the case of the late Abyssinian war, not only giving overwhelming superiority to the cause of civilisation, but deciding the issue with the least possible waste of life. But, whatever our sentiments may be in regard to war, it would be absurd to contend that we ought to abstain from invention when the

object sought to be attained is the destruction of life and property. It is our province, as engineers, to make the forces of matter obedient to the will of man; and those who use the means we supply must be responsible for their legitimate application.

It will be in the recollection of the members of this Institution who visited the Elswick Works on the occasion of the last meeting at Newcastle, that two or three small Breech-loading Rifled Guns were shown to them as novelties deserving their attention. Those guns had then very recently received the recognition of the British Government, and may be regarded as the small beginnings of a system of ordnance which has since attained a very extensive adoption in this and other countries. It was not until the principle of rifling was adopted for military fire-arms that these weapons presented much scope for the mechanician's art; but the introduction of rifling, and the change in the form of the projectile from a sphere to a pointed cylinder, brought about a complication of new conditions which it has required years of research and experiment to meet and satisfy. Passing over the subject of rifled small-arms, which of late has called forth a great amount of ingenuity and skill, I will speak of artillery, as being that division of gunnery with which I am personally connected.

The most important of all the considerations affecting modern Artillery is how to obtain the strongest possible tube with the least possible weight. Before I state my views as to the best mode of attaining this object, I must call attention to the conditions affecting the force to be resisted. When a charge of powder is fired in a gun, it is converted into gas at an exceedingly high temperature; and the pressure exerted is due even in a greater degree to the heat, than to the quantity of gas produced. But the heat evolved is not wholly realised in augmentation of pressure, a considerable part of it being absorbed by the material of the gun. The heating of a gun by firing is an effect familiar to every one, and it affords an indication both of the quantity of heat abstracted from useful effect, and also of the amazingly high temperature of the gas before it escapes from the gun. Fifty rounds fired in quick succession from a field-piece will make it so hot that it cannot be touched. Since the flame is only

in contact with the bore for about 1-150th part of a second at each discharge, it follows that the aggregate duration of the flame contact by which the gun is thus heated in fifty rounds only amounts to one-third of a second. The thin film of heated matter deposited on the surface of the bore at each discharge contributes in some measure to this rise of temperature; but we may regard the acquisition of heat from this source as fully neutralised by the cooling of the gun in the intervals occupied by loading. Thus then we are able to appreciate both the intensity of the heat of the gas, and the extent of the waste by absorption. In small guns the area of absorbing surface surrounding the charge is greater, in relation to the mass of the charge, than it is in large guns. Therefore the waste caused by the heating of the gun is also relatively greater, and the gas never attains either the same heat or the same pressure in the smaller weapon as in the larger. But the greater heat attained in a large gun adds to pressure not only directly by expanding the gas, but indirectly by accelerating the combustion of the powder. The powder must be regarded as fuel burning in a furnace, and the hotter the furnace is, the quicker the fuel will burn. It will be perceived then that the pressure of powder-gas per unit of surface is augmented by increasing the size of the gun, apart from all considerations regarding the projectile.

But the pressure of the gas is further increased in large rifled guns, by the great length of column represented by their projectiles. The resistance increases with the length of the projectile, and the pressure rises with the resistance. Augmentation of pressure is also caused by the rifled projectile having to acquire motion of rotation, in addition to that of translation; though the increase of resistance, and of consequent pressure, due to this cause is not so considerable as is commonly supposed.

For these various reasons, the introduction of the rifled principle and the enormous increase of size demanded in modern ordnance combine to intensify the pressure to a degree which taxes our utmost resources to control. The limit of the pressure actually reached in rifled guns of the largest size, when fired with English service powder, is not yet fully ascertained, but it is probably not less than 70,000 lbs. on the square inch.

Now comes the question of what construction is best adapted to resist so inordinate a strain. It was long since demonstrated by Professor Barlow that a cylinder, to possess the greatest possible resistance to a bursting force, must when out of action have its interior in a state of compression and its exterior in a state of tension. He further proved it to be necessary that the internal compression should diminish in an outward direction, and the external tension in an inward direction, up to an intermediate zone of neutrality. If these conditions were neglected, he showed that in a very thick cylinder the material forming the interior portion would be stretched to the breaking point before the exterior portion acquired any considerable tension. The interior therefore would be overstrained, while the exterior would be understrained, and the aggregate resistance would necessarily be less than if all parts were doing full duty. This reasoning is the foundation of the argument in favour of built-up guns, in which every layer of the material is stretched upon the layers beneath, and the finished structure is in the condition of internal compression and external tension demonstrated by Barlow to be that of greatest strength. The Americans have endeavoured with partial success to realise the advantage of this principle in cast-iron guns, by cooling the inside first and allowing the external portion of the metal to shrink upon the hardened interior. The Rodman cast-iron gun is made upon this system; and, considering the nature of its material, has, in some examples at least, exhibited great power of resistance, though not sufficient to enable it to be used for heavy ordnance in the rifled form. Where forged material is used for the fabrication of guns, this condition of outward tension and inward compression is unattainable except by the application of the material in successive layers, each stretched on those below. Considerations of economy or convenience may supervene to reduce the number of layers, as in the Frazer modification of coil-made guns; but theoretical perfection will be most nearly reached in that gun which is composed of the greatest number of layers. To attempt to forge large guns in single blocks is a direct violation of established theory; and the general failure which has attended such attempts is a practical proof of the truth of the theory.

The next point to consider is the best kind of material for the fabrication of guns. In determining this question, the choice clearly lies between steel and wrought-iron. I say this with no disparagement of Major Palliser's system of adapting cast-iron smooth-bore guns for rifling, by introducing a tube of coiled wrought-iron; but this method hitherto has only been applied with success to guns which, though formerly classified as heavy ordnance, are dwarfed by comparison with the ponderous guns of the present day. For these we require the greatest strength we can attain, and cast-iron cannot possibly be regarded as so efficient for enveloping the internal tube as either wrought-iron or steel. In discussing which of these two materials is best, I shall be trespassing on controversial ground. Krupp and Whitworth, both great names in gunnery, though differing widely in their views in other points, agree in this, that steel is the right material for the entire gun. I on the other hand have always advocated wrought-iron in the form of welded coil for the chief mass of the gun, limiting the use of steel to the internal tube which has abrasion to resist as well as tensile strain. The expression of my opinions upon this point may probably not be considered impartial, but I will nevertheless state the grounds upon which my preference of wrought-iron thus applied is based.

It has been found, both in Elswick and Woolwich guns, that whenever failure takes place, it almost invariably originates with that part which is made of steel. It is the steel tube which is nearly always the first to crack. So also, when the vent-pieces or closing blocks of the breech-loading guns were made of steel, their fracture was alarmingly frequent; but since wrought-iron has been substituted, such occurrences are rare. The conclusion therefore at which I long since arrived, and which I still maintain, is, that although steel has much greater tensile strength than wrought-iron, it is less adapted to resist concussive strain. This conclusion is in strict harmony with the fact that armour-plates made of steel have proved on every occasion of their trial greatly inferior to plates of wrought-iron. The experiments which I made some years ago on the toughening of steel in large masses, by immersion, when heated, in oil, led me to expect that this fragility would be obviated by that process; and I

felt sanguine that I should be able by such treatment to produce steel armour-plates of extraordinary resisting power. An armour-plate of steel was accordingly manufactured for experiment, and was tempered in a large bath of oil. Its quality was tried by test pieces cut off after tempering, and proved by tension and bending. The result showed a very high tensile strength, combined with so much toughness that I was unable to match its bending power by any sample of iron I could compare with it. The plate was then sent to Portsmouth for trial, in the fullest confidence of its success; but two shots from a 68-pounder sufficed to break it in various directions, and it was justly pronounced a failure. With these experiences before me, it is impossible that I can hold any other opinion than that the vibratory action attending excessive concussion is more dangerous to steel than to iron; and were it not necessary to provide a harder and more homogeneous substance than wrought-iron for the surface of the bore, I should entirely discard the use of steel from the manufacture of ordnance. I do not mean to contend that very strong guns may not be made of steel; but I am convinced that failures will be more frequent, and I may add more disastrous, with steel than with iron, when the conditions of trial are the same. The want of uniformity in the quality of steel continues to be another serious objection to its use; and in addition to all these considerations, the element of cost is greatly in favour of the wrought-iron coil construction over every mode of manufacture in steel.

I will now offer a few remarks upon the interesting question of the probable future of guns. Upon the solution of this question depends the pattern of future ships, and also the policy of continuing or abandoning the struggle of armour-plates against guns. From my previous remarks on the increase of pressure with which we have had to contend as we have increased the size of our guns, it might be inferred that we were now nearly reaching a limit which the strength and endurance of our material would not enable us to pass. I am not prepared to say how far we could have advanced under the recently existing conditions; but certainly every increase of size would have been attended with increase of difficulty.

A new light however has just dawned upon the subject, which entirely alters the prospect. It has become apparent that the powder we have been using can be so modified as to produce the required effect with greatly less strain upon the gun. It may appear paradoxical that there should be a limit to the theoretical advantage of increasing the initial pressure of the gas evolved in the gun; but the apparent anomaly will disappear on examination. The action of expanding gas in a gun is analogous to that of expanding steam in the cylinder of a steam engine; and we all know the advantage in the case of steam of having a high pressure to begin with, provided a steam-jacket be used to maintain the material of the cylinder at a temperature equal to that of the entering steam. But in a gun we can have no provision analogous to the steam-jacket; and it would appear that it is owing to the necessary absence of such a provision that there is a limit to the increase of initial pressure, beyond which no gain of propelling force is realised. Perhaps I shall not be fully understood without explaining this curious and important subject in a more definite manner, and I will therefore endeavour to do so.

The force exerted in a gun bears a certain relation to the heat evolved by the gasification of the charge. The greater the heat, the greater the force; for heat is nothing more than unexpended force. I have already alluded to the loss of heat by transmission to the gun, and it is evident that this transmission must be greatest in amount when the heat of the gas is highest. By using a slower burning powder, less heat and pressure are evolved at first, and the waste of heat in the stage of initial pressure being less, more heat remains for expansive action. Hence the slower burning powder is weaker at first, but stronger afterwards; and although the total quantity of gas be only the same and the maximum pressure not so great at any point, yet the aggregate pressure throughout the bore may equal that of the more energetic and more dangerous powder. This would not be so if the gun, like the steam-jacketted cylinder, could be maintained at the maximum temperature of the elastic medium within; but in the case of the gun that temperature would be far above the melting point of its own material. It is only lately that

attention has been strongly directed to the powder question in England. In Russia and Prussia, where great efforts have been made to obtain endurance with large rifled guns, powder similar in granulated form to that used in England has long been wholly discarded and superseded by powder stamped into prismatic blocks, which burn more slowly. But although we have erred in using a powder for our new ordnance so violent as to be justly designated "brutal" by the French, yet we have this satisfaction, that the ordeal which our guns have sustained with our severer powder affords an assurance of strength, which we could not have had if they had only withstood the mild description of powder with which alone Continental guns have been successfully tried. Attention is now fully awakened to the subject, and a scientific military committee is conducting experiments upon the force of different descriptions of powder. In these experiments the pressures exerted in every part of the gun are determined by the use of an instrument of exquisite delicacy invented by my friend and partner, Captain Noble. This instrument, which is a happy combination of mechanical and electrical action, indicates the velocity attained by the projectile at any number of points in the gun, and from these velocities the pressures are deduced by calculation. Thus a diagram of pressure can now be exhibited for gas in a gun, as well as for steam in a cylinder; and I think this result must be regarded as no small triumph of mechanical science.

The mitigation of initial pressure, which is now known to be compatible with the maintenance of efficiency, opens a new future for guns, and removes all doubt as to the practicability of increasing their size and power to an extent which it would be vain to follow on the side of the defence by increase in the thickness of armour. No present armour-clad vessel is proof against present guns, and there is not the slightest probability that future armour will be proof against future guns. Ships of the "Warrior" class can already be pierced with shot or shell fired at considerable ranges by even second-class guns; and the still stronger ships now in course of construction are pretty sure to be similarly overtaken in a very few years. Unless armour be invulnerable, it is of very doubtful advantage as a defence.

It will perhaps prevent the entrance of shells containing large bursting charges; but on the other hand the passage of a shot through the thick side of an armour-clad carries with it a mass of fragments that would act with terrible effect on the crew. If we cannot stop a shot, the next best thing is to facilitate its passage through. Wooden ships are out of the question, because they are combustible; but we may have ships of iron without the armour. Whatever weight we carry as armour, we lose as armament; and if we lessen the offensive power of a ship by loading her with armour, we ought to be very sure that the armour will realise its defensive purpose.

The efficiency of modern ordnance against armour-plates is dependent not only on the power of the gun, but also upon the material and form of the Projectile. Ordinary cast iron proved absolutely useless for projectiles to be used against thick armour-plates; and until Major Palliser applied the process of chilling to the manufacture of cast-iron projectiles, there was every reason to believe that hardened steel was the only material that could be used for this purpose with effect. The process of chilling gives extreme hardness to cast iron, but in point of toughness a chilled cast-iron shot is inferior to one of steel. Steel however, though much less liable to break, is more easily crushed; and this brings me to notice a curious evidence of difference in the amount of the penetrative power lost by crushing, and by breaking. A crushed projectile is always much heated by the blow, but the fragments of a chilled projectile remain cool. Hence we see that crushing detracts more from the power of a projectile than breaking, because the heat developed in a projectile by striking a plate is a criterion of the amount of force expended upon the projectile instead of upon the plate. We accordingly find that a Palliser shot breaking by impact will nevertheless pierce more easily than a steel shot which remains whole but yields to crushing. As to the proper form of head to be given to the projectile for piercing armour, it will be remembered that a few years ago this question was hotly contested between the supporters of round heads and flat heads; but, as often happens in the case of human contentions not limited to the sphere of mechanical engineering, both parties

were afterwards proved to be wrong. When Major Palliser brought forward his chilled projectile, he advocated a pointed head, and with the new material he was found to be right. Major Palliser has competitors on the continent, whose claims I cannot pretend to weigh; but in this country at all events he is entitled to the honour of improving both the material and the form of the projectile, thereby greatly increasing the penetrative power of our artillery, and at the same time effecting an enormous economy in the manufacture of projectiles.

The most legitimate use of instruments of war is for the purpose of home defence; and I therefore proceed with satisfaction to notice a class of inexpensive vessels requiring no armour, and adapted to render the heaviest artillery available for the protection of our shores and harbours. Until very recently there seems to have been an impression that large guns required large vessels to carry them; but the fallacy of this idea has been practically shown by the proving barge of the Elswick Works, which is a mere floating gun-carriage. This little vessel, which is only sixty tons burden, is continually used without difficulty for the trial of twelve-ton guns at sea, even when the swell is considerable. This proving barge was the origin of Mr. Rendel's idea of the now well-known gunboat "Staunch." The Elswick barge has no steam power, and thus represents the minimum of size; but the "Staunch" is provided with steam power, both for propulsion by means of twin screws, and for working her twelve-ton gun. She is therefore somewhat larger than the Elswick barge, and yet so small as to be very inexpensive, and at the same time a very difficult mark to hit. To burden such a vessel with armour would at once increase her size and her cost, thus rendering her more easy to hit and more expensive to lose. A simple screen might perhaps be advantageously applied as a protection against shrapnel; but thick armour, if used at all, should be reserved for ocean ships. I have so recently published my views on the subject of this vessel that I need not now repeat them further, merely observing that guns of the largest size now made or ever likely to be made may be mounted in vessels similar to the "Staunch," without increasing their tonnage in more than a proportionate degree.

Another recent invention highly favourable to defence is the celebrated Gun-Carriage of Captain Moncrieff. By the ingenious arrangement of this carriage, the recoil of the gun operates in a downward direction, and in descending it lifts a counterweight, which, when liberated after loading, raises the gun again to the height necessary for firing over the edge of a parapet. By this mechanism the gun is handled with almost perfect security to the men, and is itself exposed in the smallest possible degree and only for a few seconds while being fired. No embrasures being required, the gun is not restricted in lateral range. This is the characteristic advantage of the Barbette system of mounting guns, which has however the fatal objection of exposing both guns and gunners. Embrasures are always a source of trouble in fortifications. They not only *admit* but *guide* projectiles into the fort at the very points where guns are placed. In iron defences the opening for the gun is even more objectionable. Not only does it weaken the whole structure, but it serves to break up cast-iron shot striking on the edge, and thus to occasion terrible destruction inside. I may state as a fact, communicated to me by a Brazilian officer on whose testimony I rely implicitly, that in the late Paraguayan war in which he was engaged he saw whole gun-crews swept away in the Brazilian iron-clads by common cast-iron round shot, contemptible for piercing even the weakest armour, but which, striking the edge of the port, entered the ship in a torrent of fragments. The Moncrieff gun-carriage gives great additional value to earthworks, and in fact may be used in mere pits which would be wholly invisible to an enemy. It will probably also prove to be available, in combination with iron defences, as a means of avoiding the objection of port-holes; and it will have the effect of placing muzzle-loading guns on a par with breech-loaders in regard to security and ease of loading. Captain Moncrieff's invention will play a very important part in defensive operations, and will greatly reduce the expense of fortifications.

Many other instances may be cited in illustration of the tendency of mechanical progress to favour defence. Thus the increasing size of guns renders them difficult to transport for offensive use abroad, but creates no impediment to their defensive application at home.

Or, if we look to the nautical side of the subject, we see that the conditions sought to be attained in war-ships for aggressive action involve enormous cost, and that the great size of these vessels makes them favourable targets for the fire of opposing artillery. On the other hand, the vessels required for coast and harbour defence are of cheap construction, and their small size and facility of movement give them the advantage of being difficult to hit. The Moncrieff carriage is applicable almost exclusively to defensive purposes; and the same may be said of torpedoes, which by many ingenious contrivances have recently been rendered most formidable obstacles to naval attacks upon sea-ports. The tendency therefore of mechanical invention as applied to war is to discourage aggression, and thus to maintain peace. We may consequently hope that it will hasten the arrival of a period when civilised nations will abandon the arbitrament of arms, and settle their differences by rational and peaceable methods.

But while I defend the mechanical branch of military science from all imputation of serving the cause of war, I do not forget that it is to the civil branch of mechanical engineering that the honour of promoting the friendship of nations especially belongs. It is by the facilities it gives to intercourse and exchange, and by the reciprocal benefits which flow therefrom, that it teaches men how much they have to gain by peace, and to lose by war.

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A vote of thanks was passed to the President for his valuable and interesting Address, on the motion of Mr. Ramsbottom, Vice-President.

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# CAPT. NOBLE'S INSTRUMENT FOR DETERMINING THE VELOCITY OF PROJECTILES IN DIFFERENT PARTS OF THE BORE OF A GUN.

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After the President's address, Captain Noble exhibited and explained his Instrument for determining the Velocity of Projectiles in different parts of the bore of a gun, and showed experiments in illustration of its action.

The object of this instrument is to render distinctly visible and to register the exceedingly minute intervals of time occupied by the passage of a shot through successive distances in the bore of a gun; and this is effected by registering these intervals of time, by the aid of electric currents, upon a recording surface travelling at a uniform and very high speed, so that the minute intervals of time are represented by intervals of space that are of sufficient magnitude to be readily appreciable. The instrument consists of two portions: first, the mechanical arrangement for obtaining the extremely high speed of the recording surface, and maintaining that speed uniform: and second, the electric apparatus for registering upon this surface the exact instants of time at which the shot passes certain stated points in the bore of the gun.

The first part of the instrument, for obtaining a very high and uniform speed of the recording surface, consists of a series of six thin metal discs, each 36 inches circumference, fixed at intervals upon a horizontal revolving shaft, which is driven at a very high speed by a heavy descending weight, arranged according to a plan originally proposed by Huyghens, through a train of gearing multiplying 625 times. If the speed of rotation of the discs were got up through the action of the falling weight alone, a very considerable waste of time would be occasioned; and to obviate this

inconvenience a special arrangement is provided for obtaining approximately with great rapidity the required velocity of the discs, by means of a handwheel connected temporarily with the gearing. The sound emitted by the rapid rotation of the discs and gearing serves as an indication of the uniformity of speed, a very slight variation in speed being sufficient to alter the acuteness of the sound to an extent that is readily detected by the ear. The actual velocity is ascertained by a clock connected with one of the slower wheels of the train; and the time of making each 5 revolutions of this wheel, or 625 of the discs, is shown correct to 1-10th of a second by the clock. The speed usually employed in the working of the instrument is about 1000 inches per second lineal velocity at the circumference of the revolving discs, so that each inch travelled at the circumference of the discs at that speed represents one thousandth part of a second; and as the inch is subdivided by a vernier and magnifying eye-piece into a thousand parts, a lineal representation at the circumference of the discs is thus obtained of intervals of time as minute as one millionth of a second. As a minute variation in speed would make a difference in measurement at the circumference of the discs, the uniformity of rotation maintained by the descending weight is tested on each occasion of experiment by three observations, one immediately before, one during, and one immediately after the experiment, the mean of these being taken for the average speed during the experiment. With a little practice there is no difficulty in arranging the instrument so that the discs may rotate either quite uniformly or at a rate very slowly increasing or decreasing; and it is found that the probable error then arising in the determination of the time occupied by 625 revolutions of the discs rarely amounts to so much as 1-10th of a second, the total time of making each 625 revolutions being about 23 seconds. The uniformity of revolution during each experiment may consequently be considered practically perfect, as the total time of observation in the passage of a projectile along the length of a gun is generally less than one third of a single revolution of the discs. The maintenance of the speed with so great a degree of uniformity is obtained by means of very great accuracy of workmanship in all parts of the mechanism.

For accomplishing the second portion of the operation, namely the registering of the exact instants of time which it is desired to determine, the six revolving discs are each covered on the edge with a strip of white paper, and are all in connection with one extremity of each of the secondary wires of six electrical induction coils; the other extremity of each secondary wire, carefully insulated, is brought to a discharger opposite the edge of its corresponding disc, and is fixed so as to be just clear of the revolving disc. When an electric spark is passed from one of the wires to its corresponding revolving disc, a minute hole is perforated in the paper covering on the edge of the disc, marking the point of the disc that was opposite to the wire at the instant of the spark passing; but as the situation of this hole in the paper would be very difficult to find on account of its extreme minuteness, the paper is previously blackened over with lamp-black, and the position of the hole is then readily seen by a distinct white spot being left on the blackened paper on the edge of the disc, in consequence of the lamp-black at that point having been burnt away by the electric spark, so that the white paper is shown beneath. As the points of the six wires at the edge of the discs are all arranged in the same horizontal straight line, parallel with the axis of the revolving discs, an absolutely simultaneous passage of the six electric sparks causes the spots produced upon the six discs to be all exactly in the same horizontal straight line, at whatever speed the discs may be revolving; but any interval of time between the sparks is represented by a corresponding circumferential distance between the spots on the different discs, this distance being proportionate to the speed at which the discs are revolving. Thus when the discs are running at the circumferential speed of 1000 inches per second, an interval of 1-1000th part of a second of time between any two of the sparks causes the spots made upon the two corresponding discs to be separated by a distance of 1 inch measured at the circumference of the discs.

The mode of connecting the primary wires of the induction coils to the bore of the gun, in such a manner that an electric current shall be induced and a spark produced at the instant of the shot passing each wire in succession, is shown in Figs. 1 and 2,

Plate 44, representing a longitudinal and a transverse section of the bore B of the gun, along which the shot A is moving in the direction of the arrow. A hollow plug C is screwed into the side of the gun, carrying at its inner extremity a hinged finger D, forming a trigger, which is made with an incline at the tail end, projecting slightly within the bore of the gun, as shown on the right-hand side in Fig. 1 and in Fig. 2; and the trigger is held up in this position by the primary wire, which passes in at one side of the plug C, then through a hole in the trigger D, and out again at the other side of the plug. When the shot is fired, it presses the trigger D outwards, as shown on the left-hand side in Fig. 1, and thereby cuts the wire through; and the consequent breaking of the current in the primary wire induces a current instantaneously in the secondary wire, causing an electric spark at the same instant to pass from the point of the wire to the disc, its passage being marked by the spot left upon the paper edge of the disc.

The action of the apparatus was exhibited by Captain Noble by firing a shot from a musket, the bore of which was connected with the six discs of the instrument by six wires arranged at increasing intervals along the length of the barrel; the distances between the successive wires, commencing at the breech end, were $\frac{1}{2}$ inch, $1\frac{1}{2}$ inch, 3 inches, 5 inches, and $7\frac{1}{2}$ inches. At the instant of firing, the six sparks were seen to pass at the edge of the discs, all apparently at the same moment; but on stopping the rotation of the discs, it was seen that the spots left by the passage of the sparks were situated at increasing intervals round the circumference of the successive discs, extending to a distance of about 2 inches, the visible intervals of space being exactly proportionate to the minute intervals of time occupied by the shot in passing through the successive intervals in the bore of the gun. For the purpose of illustrating the correct action of the instrument, a second experiment was exhibited with all the six wires placed together across the muzzle of the gun, so that the shot when fired should sever them all simultaneously. The discs were then made to revolve at the same speed as in the previous experiment, and the shot was fired; and on stopping the discs, the six spots made

by the passage of the sparks were found to be all exactly in the same horizontal straight line, parallel with the axis of the discs, showing that the six sparks had all occurred at precisely the same instant of time, and that there was consequently no irregularity in the action of the instrument from inequality in rate of transmission of the electric currents by the six separate wires.

The instantaneous action of the electric currents obtained by the use of an induction coil admits of the observations being taken by means of this instrument at very short intervals along the bore of the gun; and as many as six observations have been obtained in this way in a length of only 9 inches along the bore. In the first trials of this instrument three years ago, it was attempted, on account of the expense of induction coils, to employ electro-magnets for recording on the discs the moment at which the current of electricity was broken by the passage of the shot. In this arrangement a pointer pressed towards the revolving disc by a strong spring was held back just clear of the disc by means of a powerful electro-magnet; and when the current of electricity was broken, the magnet becoming de-magnetised released the pointer, which registered by a scratch on the prepared surface of the disc the moment of the shot passing. By this means tolerably accurate results were obtained, as long as it was attempted to work with two discs only; but even with two discs considerable irregularities occurred in the results, owing apparently to almost inappreciable variations in the strength of the electric currents; in spite of these difficulties however, the velocities at different points of the bore of a Lancaster rifle were determined with tolerable accuracy. But when it was attempted to use more than two discs, the irregularity of action of the instrument was so great that this mode of registration had after many trials to be abandoned, and the induction coils were adopted instead.

In order to measure the circumferential distances between the spots marked on the successive discs in any experiment, the shaft of the revolving discs is disconnected from the gearing of the instrument; and by means of a micrometer screw each disc in succession is then turned backwards until the spot upon its edge is brought exactly opposite a magnifying eye-piece, which slides

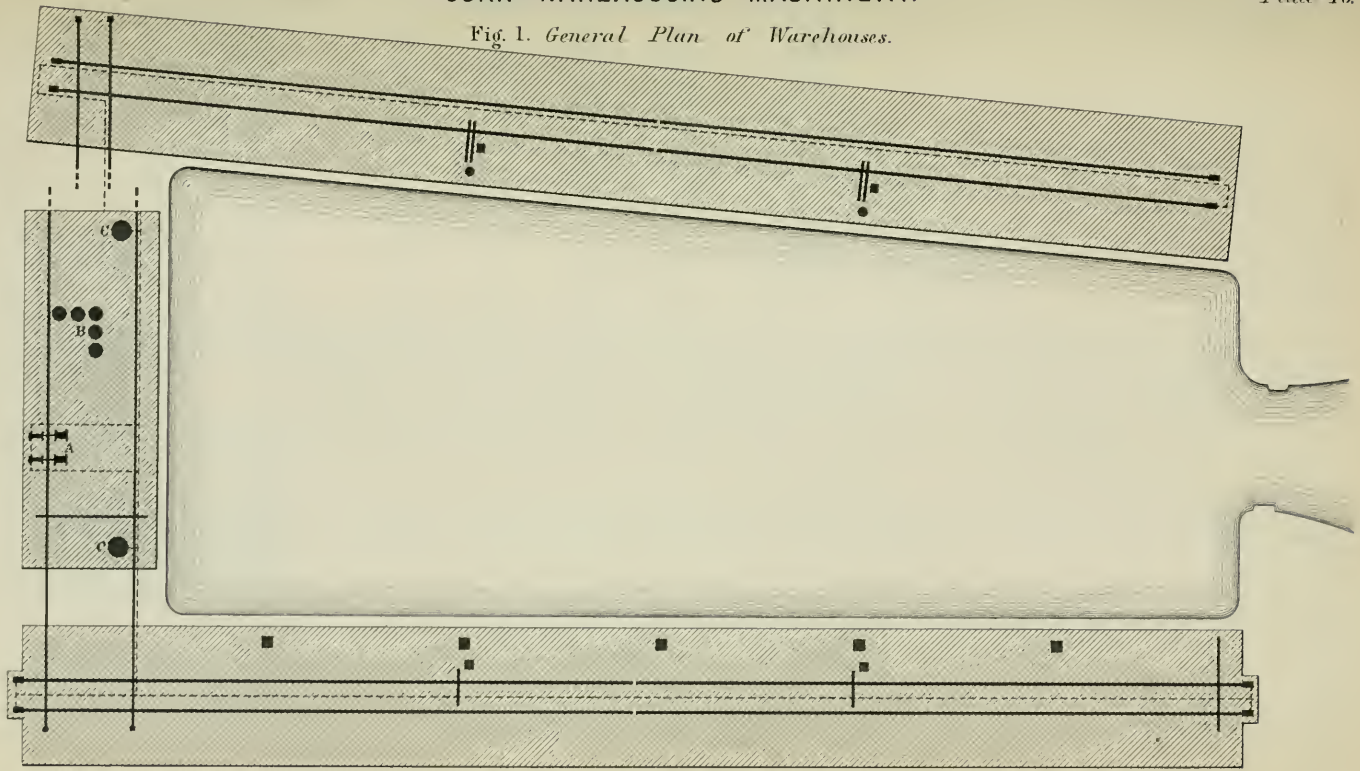
horizontally along a bed parallel to the axis of the discs. The divided head of the micrometer screw shows the circumferential distance through which each disc is turned backwards, which is then recorded; and by setting out in the form of a diagram the circumferential distances thus determined between the spots marked upon the successive discs, a "time" curve is obtained, as shown by the strong dotted lines in Figs. 3 and 4, Plate 45. The position of the vertical lines represents the position of the six wires fixed at successive points C C along the bore of the gun B; and the vertical length of each line, being the circumferential distance of the spot on the corresponding disc, represents the time occupied by the shot A in reaching the corresponding point in the gun from the moment of starting. From the "time" curves are obtained by calculation the "velocity" curves, shown by the fine lines in Figs. 3 and 4; and from these again the "pressure" curves, shown by the strong full lines, are also arrived at by calculation.

The practical application that has been made of this instrument has been for the purpose of ascertaining the relative strains to which guns are subjected by the employment of different sorts of gunpowder, fast-burning and slow-burning; and the curves shown in the diagrams Figs. 3 and 4, Plate 45, are some of the actual curves that have been obtained in the experiments made upon this subject. In Fig. 3 are shown the curves given by a fast-burning powder, and in Fig. 4 those obtained with a slow-burning powder; and a comparison of the two shows that in this instance, although the shot took about twice as long time in passing along the length of the bore of the gun when fired by the slow-burning powder, yet the velocity at which it left the muzzle of the gun was about the same as when fired by the fast-burning powder; while at the same time the important advantage is here gained with the slow-burning powder that the maximum strain thrown upon the gun in firing is only about half of that to which the gun is subjected in firing the same shot with the fast-burning powder.

# CORN WAREHOUSING MACHINERY.



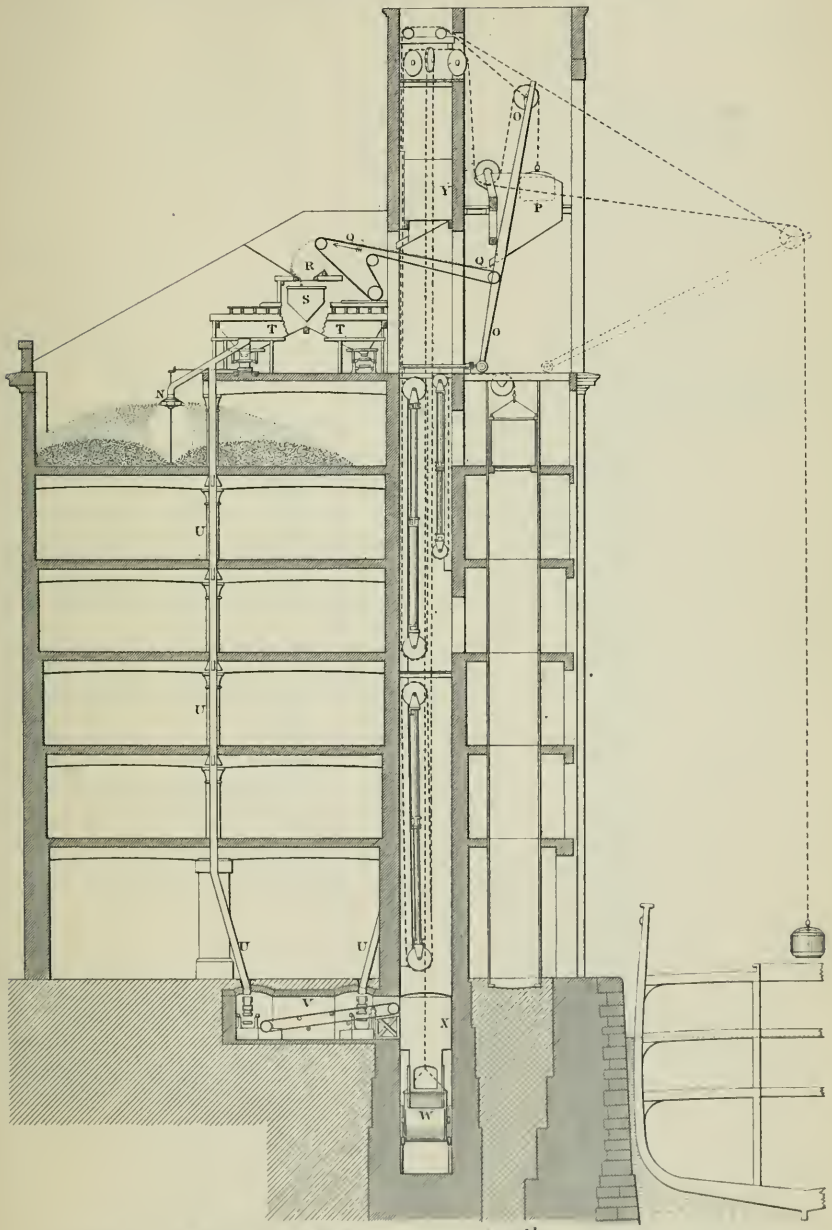
Fig. 1. *General Plan of Warehouses.*




*(Proceedings Inst. M. E. 1869.)* *Scale* $^1/_{1200}$*th*

100 50 0 100 200 300 *Feet.*

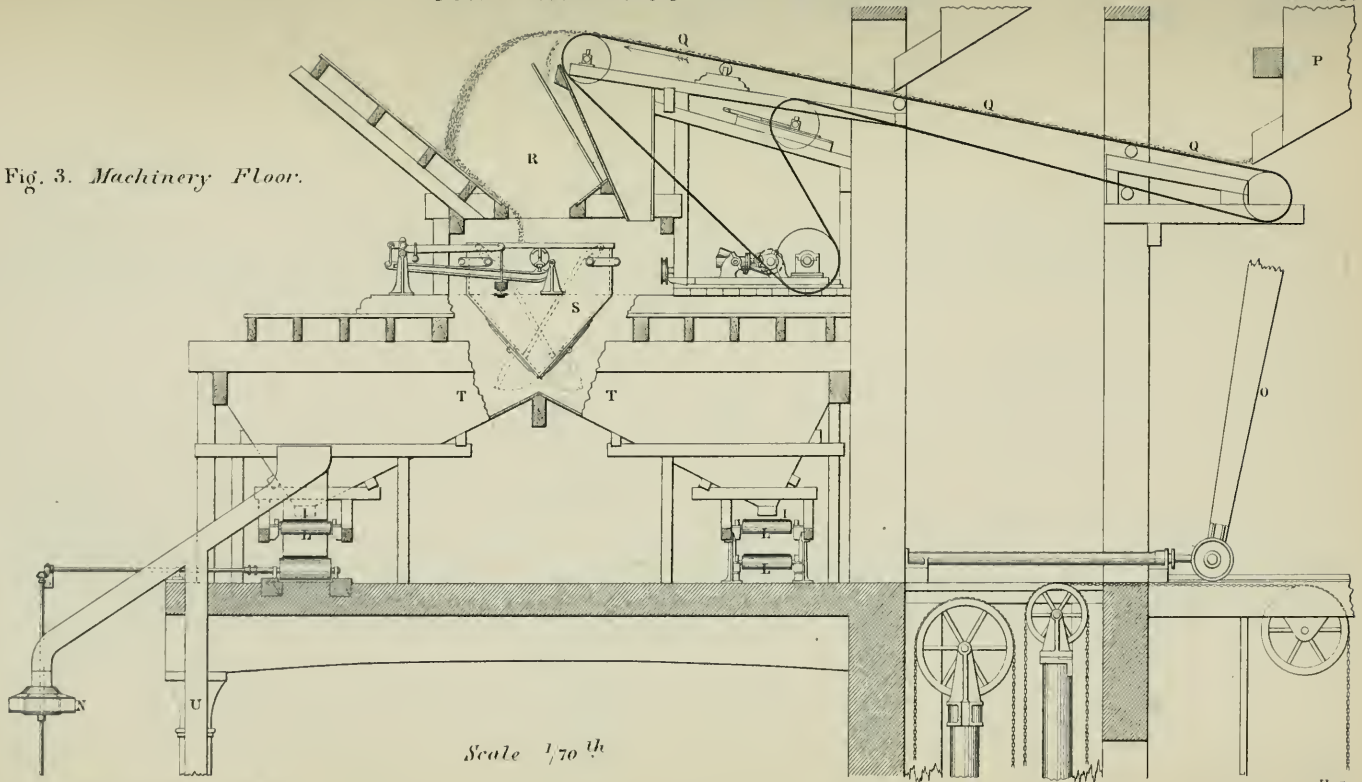
Fig. 2. *Transverse Section of Warehouse.*




*(Proceedings Inst. M.E. 1869.)* *Scale* 1/300 th

10 5 0 10 20 30 40 50 60 70 80 Feet.

Fig. 3. *Machinery Floor.*




*(Proceedings Inst. M.E. 1869.)*

# CORN WAREHOUSING MACHINERY.

*Plate 49.*

*Travelling Band and Gear.*

Fig. 4. *Side Elevation.*

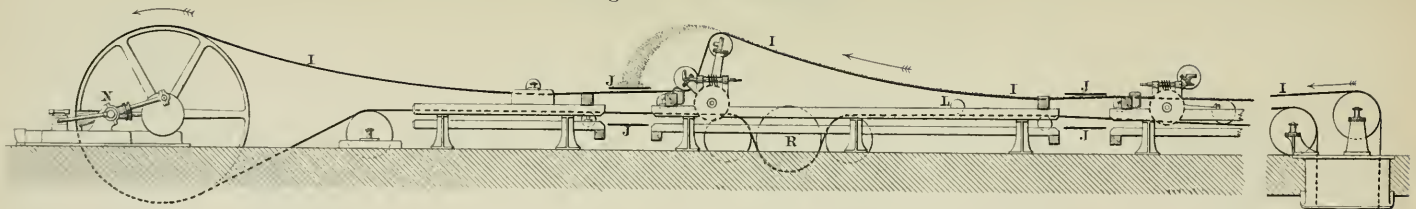
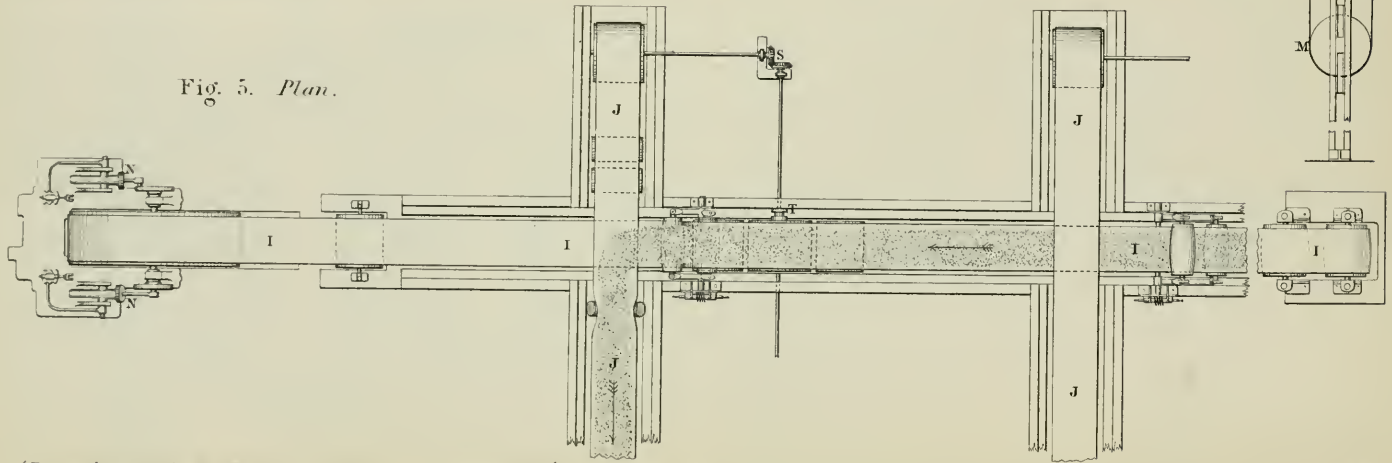



Fig. 5. *Plan.*




*(Proceedings Inst. M. E. 1869.)*

*Scale* $\frac{1}{70}$ *th*

*Throwing-Off Apparatus.*

Fig. 6. *Side Elevation.*

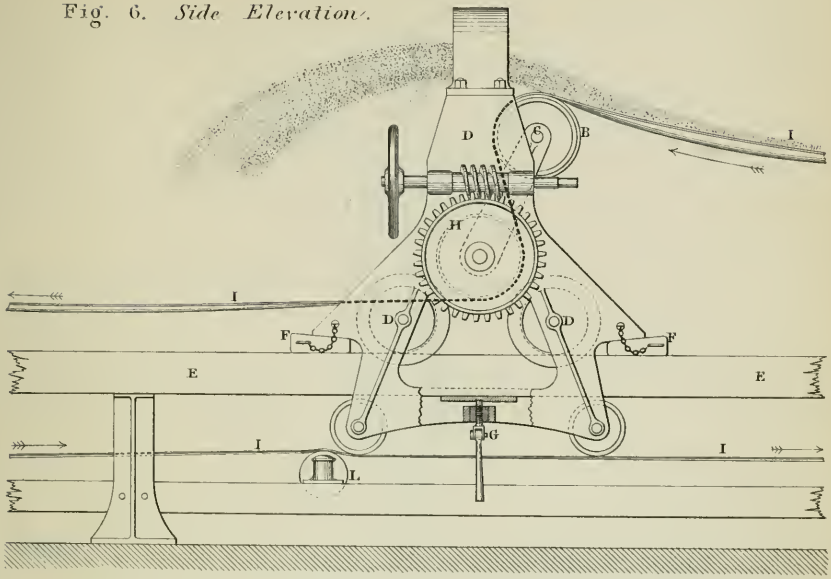
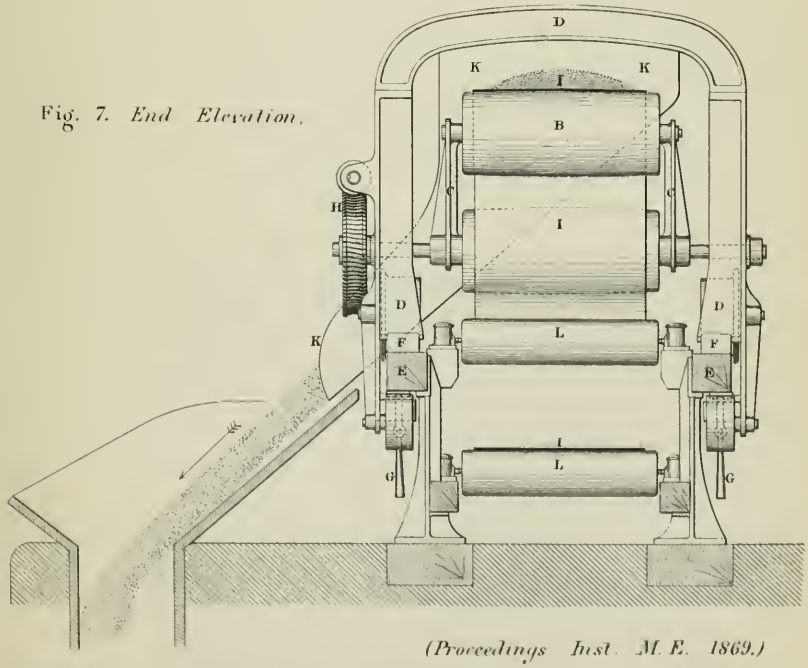



Fig. 7. *End Elevation.*




*(Proceedings Inst. M. E. 1869.)*

*Scale* $\frac{1}{20}$ *th*

10 5 0 10 20 30 40 *Inches.*

*Distributing Fan.*

Fig. 8. *Vertical Section.*

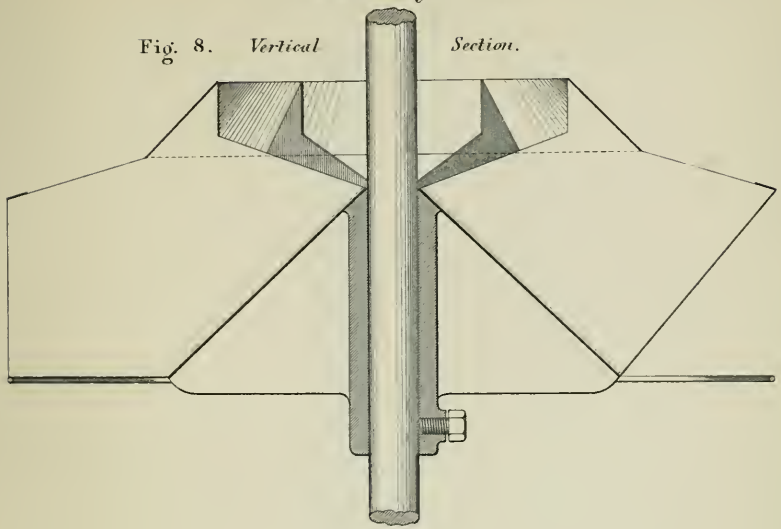
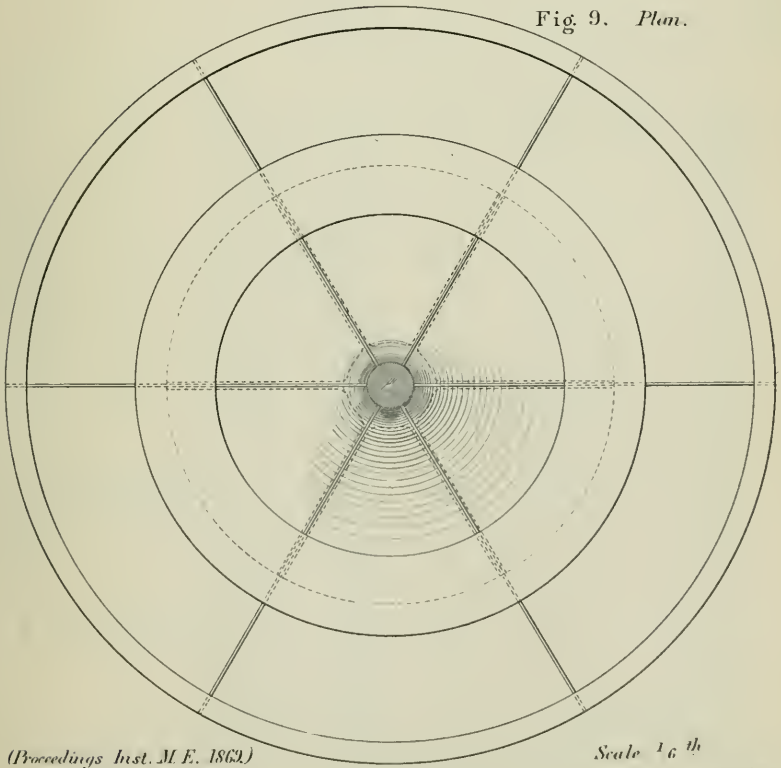


Fig. 9. *Plan.*



*(Proceedings Inst. M.E. 1869.)*

*Scale* $\frac{1}{6}$ *th*

0 5 10 15 20 *Inches.*

*Elevator*
*for lifting Grain*
*in warehouse.*

Fig. 10.
*Discharging.*

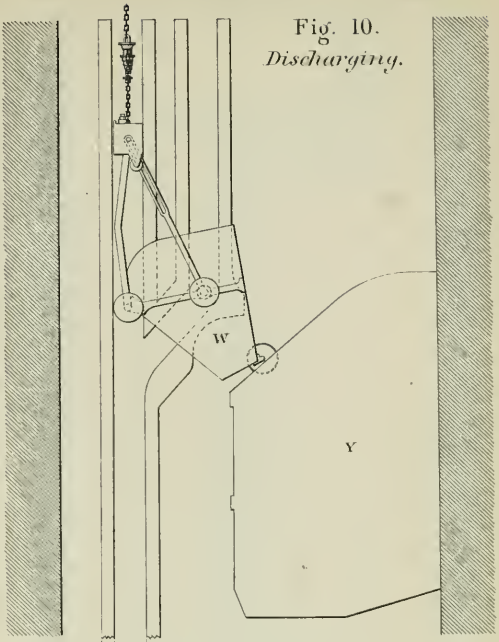



Fig. 12. *Front View.*

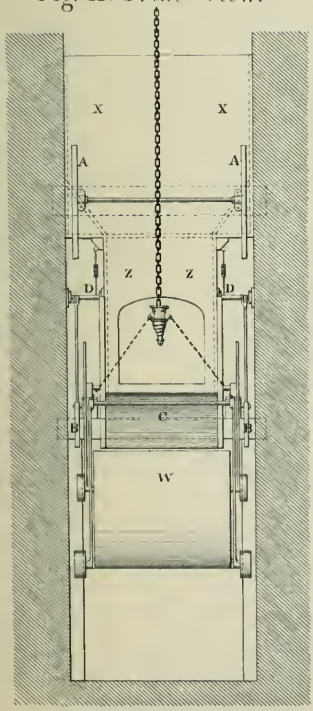
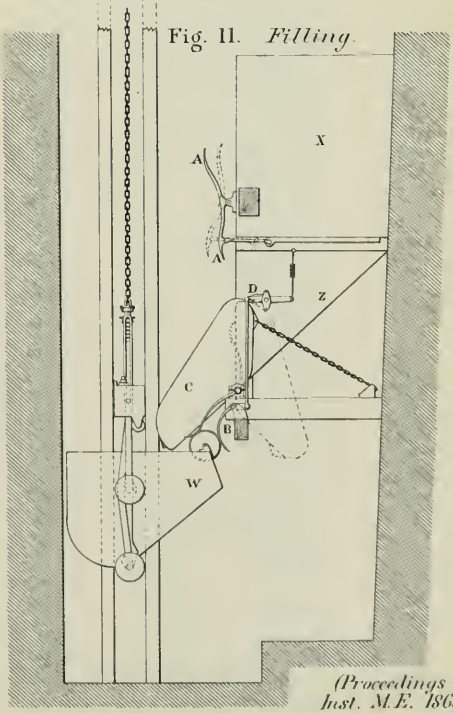



Fig. 11. *Filling.*




(*Proceedings Inst. M.E. 1869*)

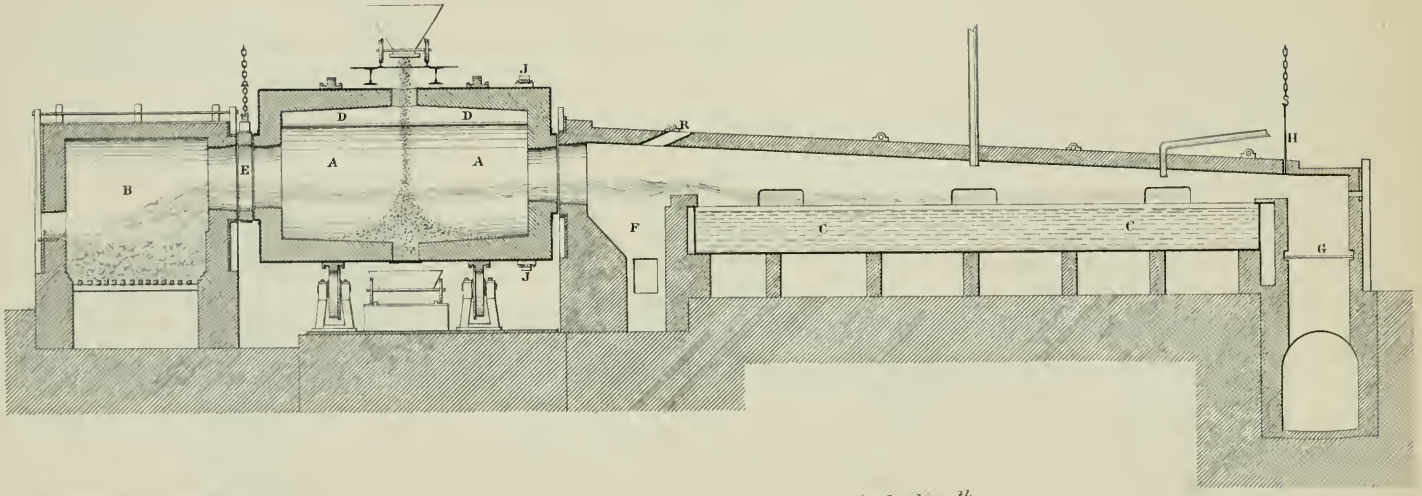
*Scale* 1/80 *th.*

0 5 10 15 20 *Feet.*

# REVOLVING CHEMICAL FURNACE.

*Plate 53.*

Fig. 1. *Longitudinal Section through Revolving Cylinder and Evaporating Pan.*




*(Proceedings Inst. M.E. 1869.)*

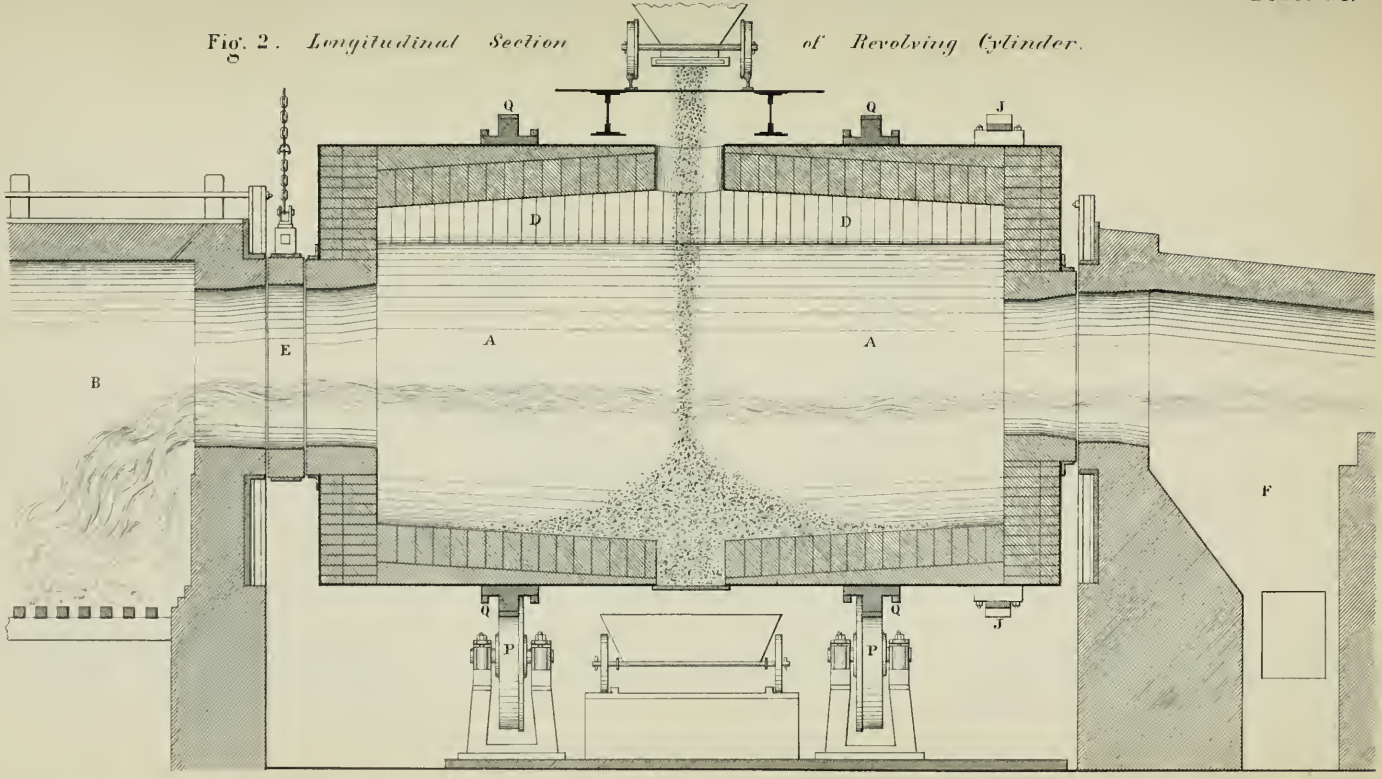
*Scale 1/120 th*

10 5 0 10 20 30 40 50 Feet.

# REVOLVING CHEMICAL FURNACE.

*Plate 54.*

Fig. 2. *Longitudinal Section of Revolving Cylinder.*




*(Proceedings Inst. M. E. 1869.)*

*Scale 1/30th*

0 1 2 3 4 5 6 7 8 9 10 11 12 Feet.

# REVOLVING CHEMICAL FURNACE.

*Plate 55.*

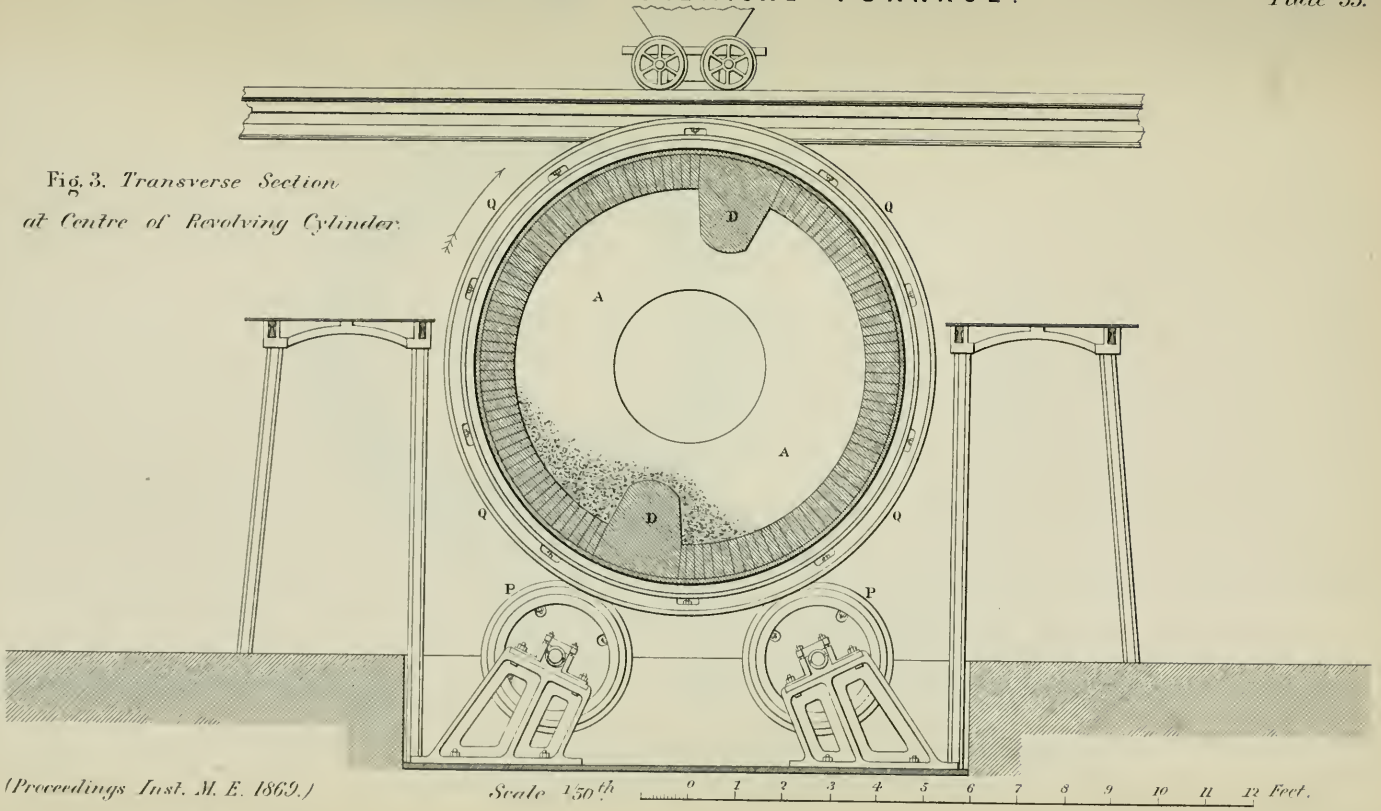



Fig. 3. *Transverse Section at Centre of Revolving Cylinder.*

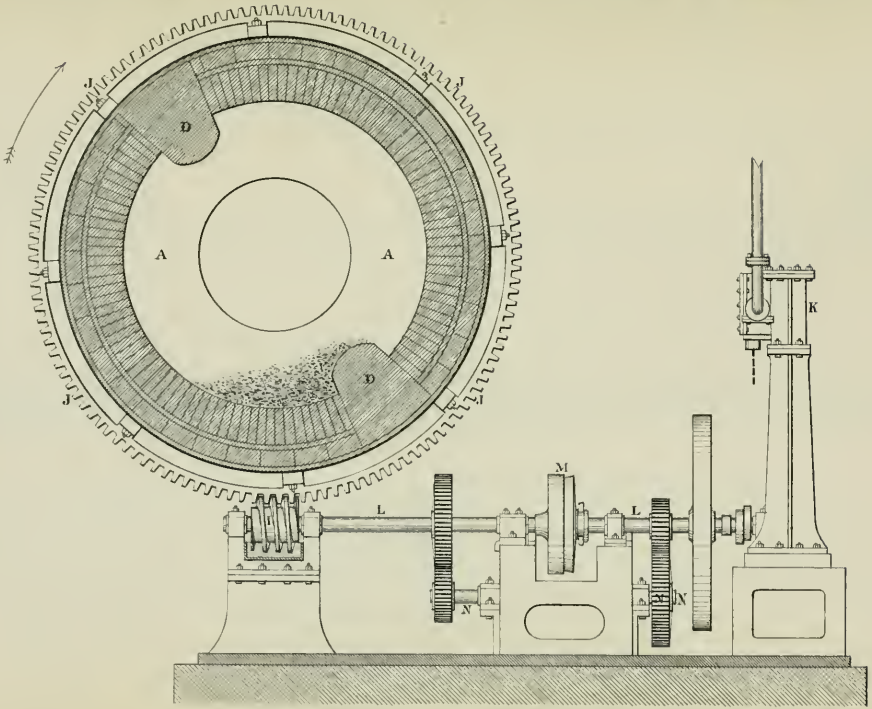
*(Proceedings Inst. M. E. 1869.)*

*Scale* $\frac{1}{150}$*th* 0 1 2 3 4 5 6 7 8 9 10 11 12 *Feet.*

# REVOLVING CHEMICAL FURNACE.

*Plate 56.*

Fig. 4. *Transverse Section at End of Revolving Cylinder*




*(Proceedings Inst. M. E. 1869.)*

*Scale* 1/50 *th*

0 1 2 3 4 5 6 7 8 9 10 11 12 Feet.

# WIRE-ROPE NAVIGATION.



*10 horse power Tug on Canal de Charleroi.*

Fig. 1. *Side Elevation.*

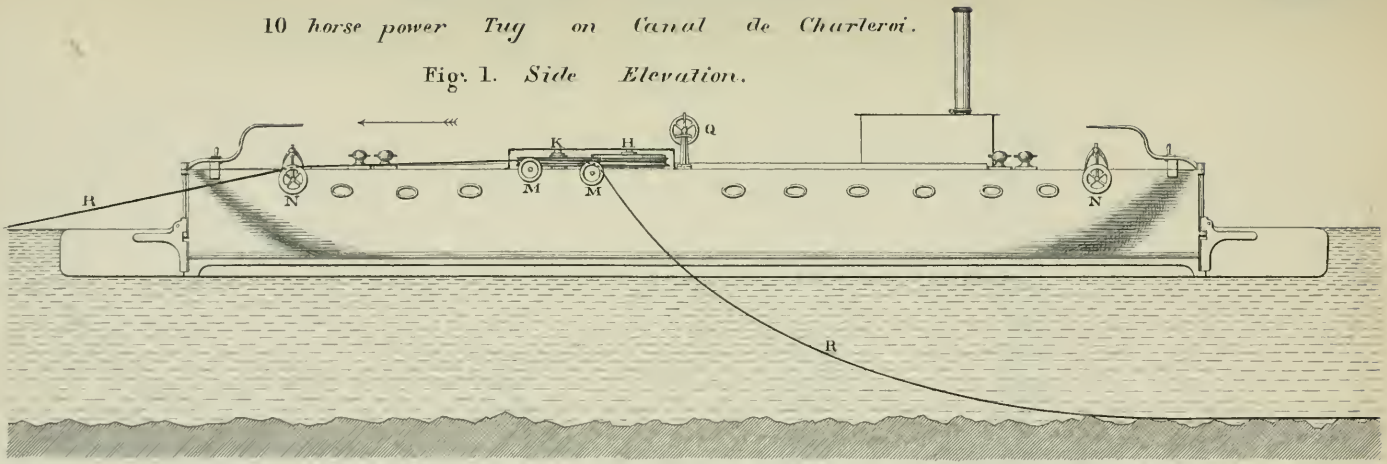
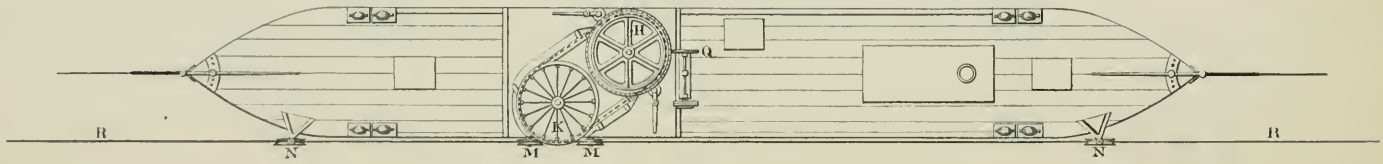



Fig. 2. *Plan.*

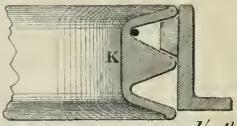



*(Proceedings Inst. M.E. 1869)* *Scale* 1/150th 10 5 0 10 20 30 40 Feet.

10 *horse power Tug on Canal de Charleroi .*

Fig. 3. *Side Elevation of Engine and Winding Gear.*
*Scale 1/40th.*

Fig. 5. *Section of Double-grooved Guide Pulley and Rope Guard .*




*Scale 1/10th.*

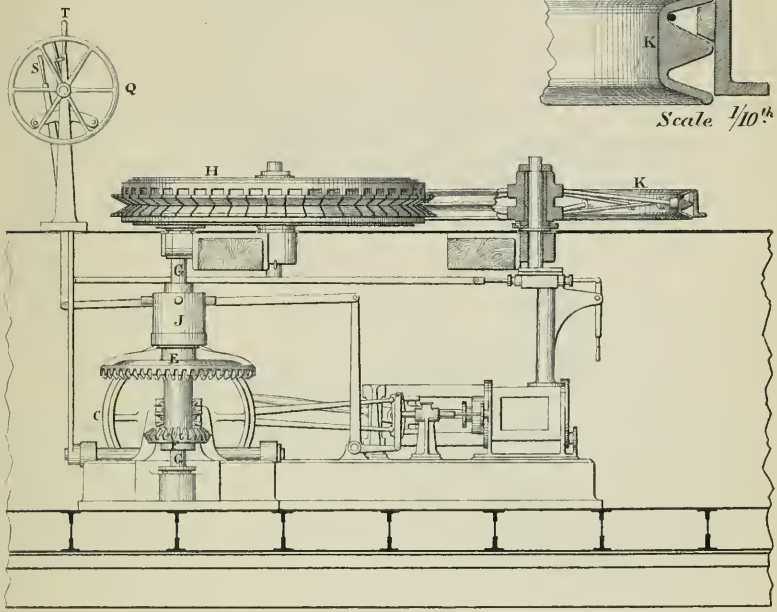
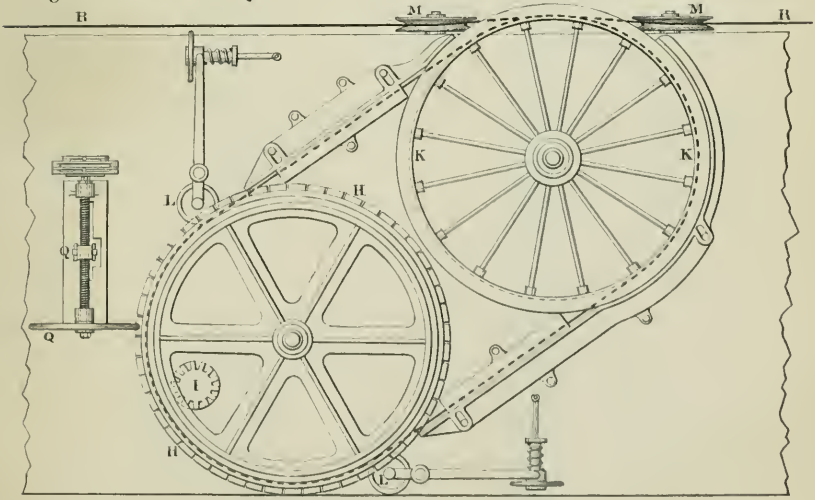



Fig. 4. *Plan of Clip Drum and Double-grooved Guide Pulley.*




*(Proceedings Inst. M. E. 1869)*

*Scale 1/40th.*

0 1 2 3 4 5 6 7 8 9 10 Feet.

10 *horse power Tug on Canal de Charleroi.*

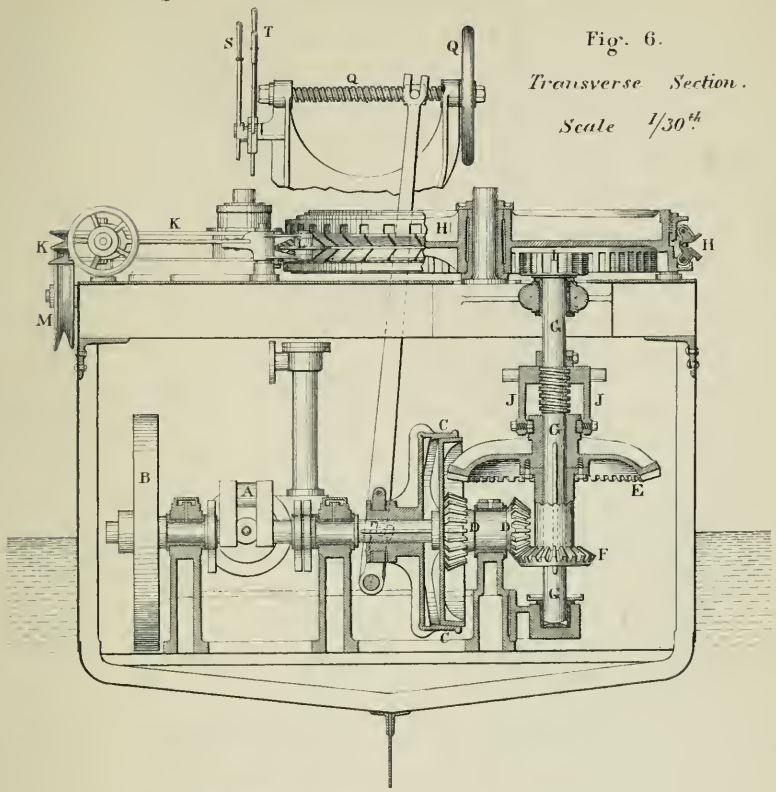



Fig. 6.

*Transverse Section.*

*Scale 1/30th.*

Fig. 7. *Leading Pulley.*

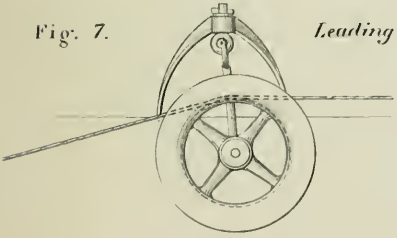


Fig. 8.

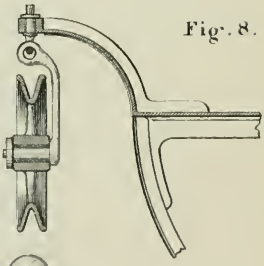


Fig. 9. *Balanced Leading Pulley.*

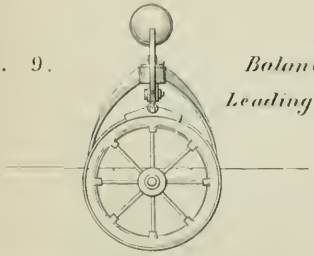
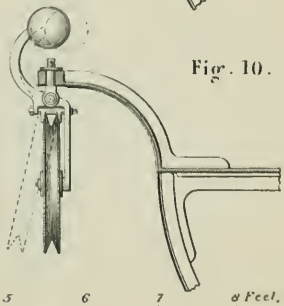


Fig. 10.



*(Proceedings Inst. M.E. 1869.)* *Scale 1/30th.*

0 1 2 3 4 5 6 7 8 Feet.

# WIRE-ROPE NAVIGATION.

14 *horse power Tug on River Meuse.*

Fig. 11. *Side Elevation.*

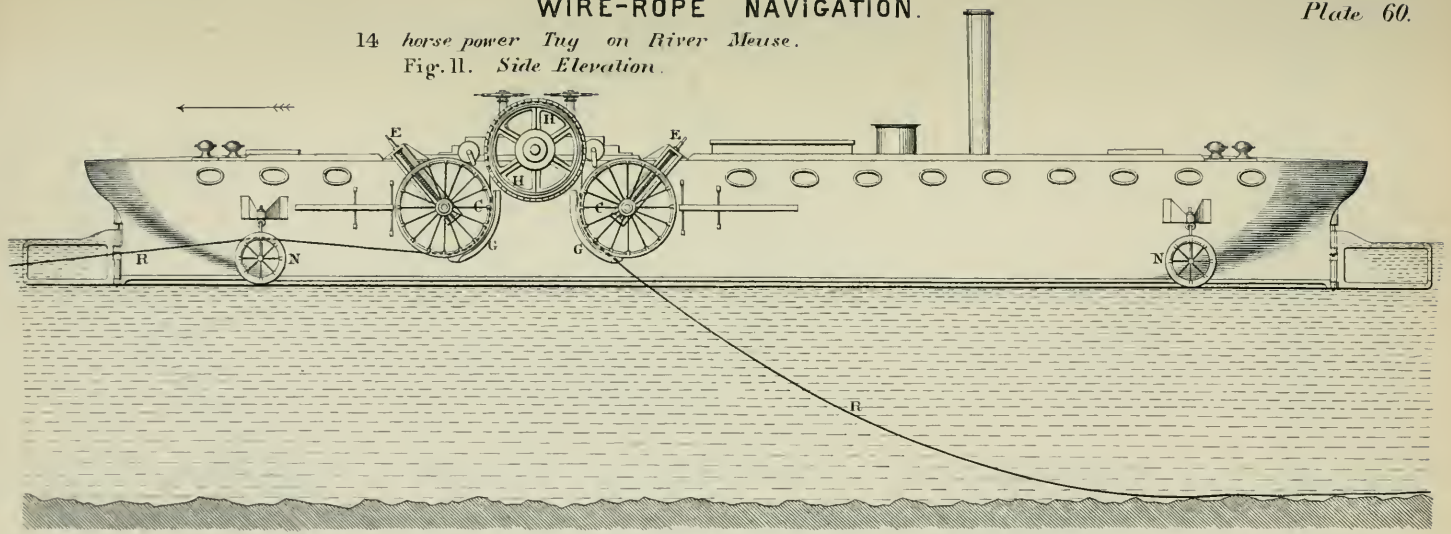
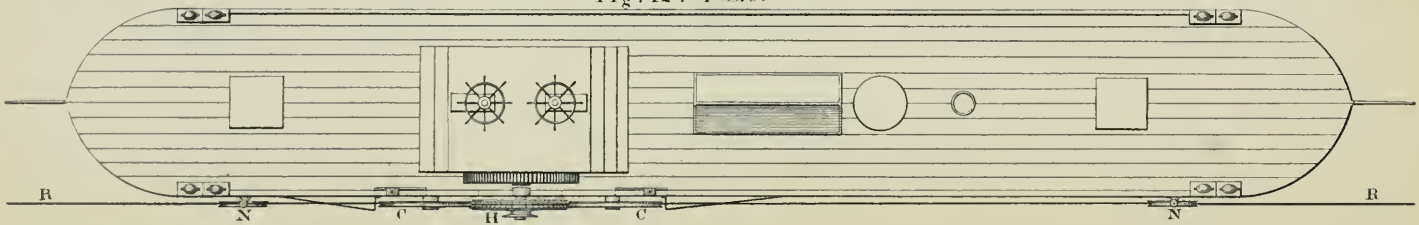



Fig. 12. *Plan.*




(*Proceedings Inst. M. E. 1869.*) *Scale* 1/150th. 10 5 0 10 20 30 40 Feet.

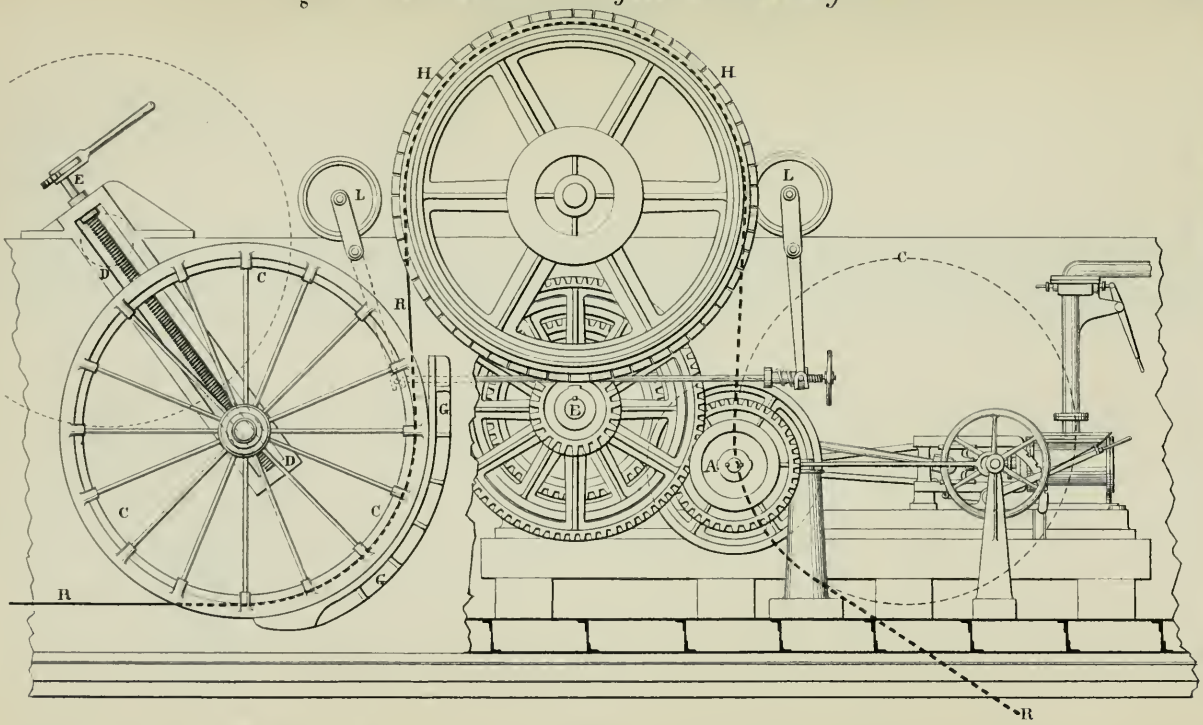
# WIRE-ROPE NAVIGATION.

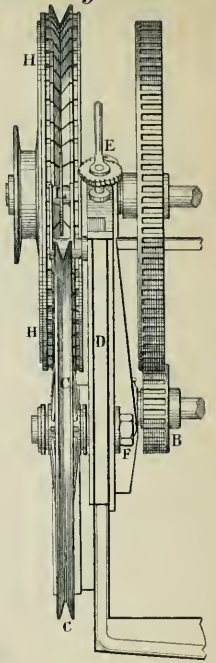
*14 horse power Tug on River Meuse.*

Fig. 13. *Side Elevation of Engine and Winding Gear.*

*Plate 61.*

Fig. 14. *End Elevation of Winding Gear.*




(*Proceedings Inst. M. E. 1869*)

Scale 1/40th.

0 1 2 3 4 5 6 7 8 9 10 Feet.

# WIRE-ROPE NAVIGATION.

*Steam Tug with Portable Engine.*

*Plate 62.*

Fig. 15. *Side Elevation.*

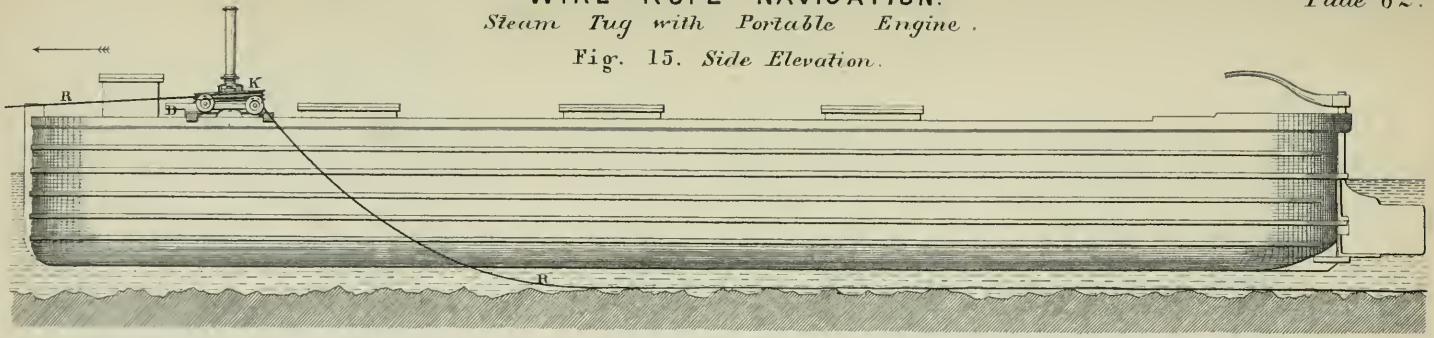
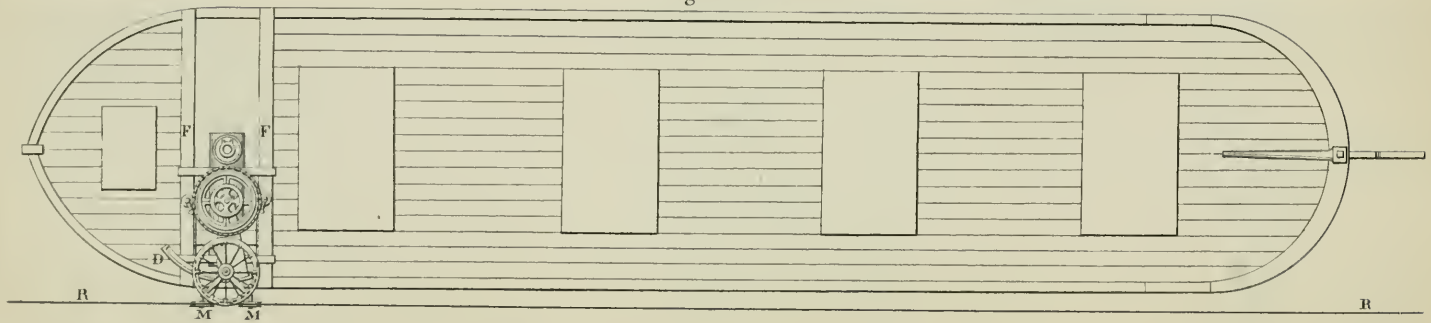



Fig. 16. *Plan.*




*(Proceedings Inst. M.E. 1869.)* *Scale* 1/150th.

10 5 0 10 20 30 40 Feet.

*Portable Engine for Steam Tug.*

Fig. 17. *Side Elevation.*

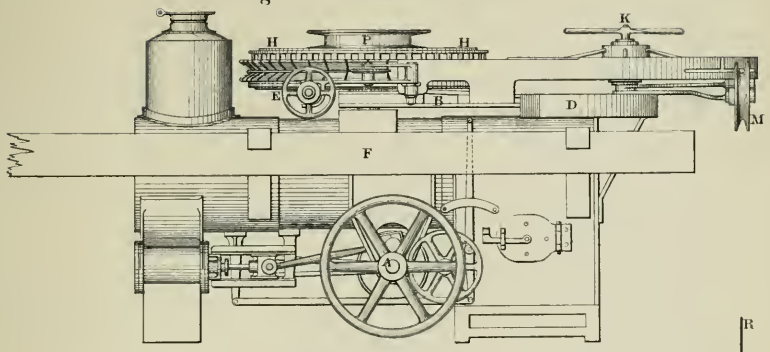



Fig. 18. *Plan.*

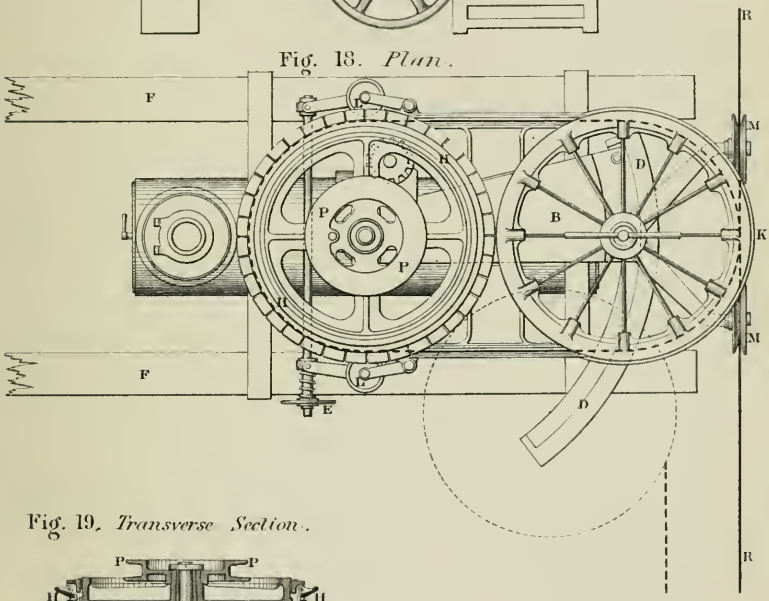



Fig. 19. *Transverse Section.*

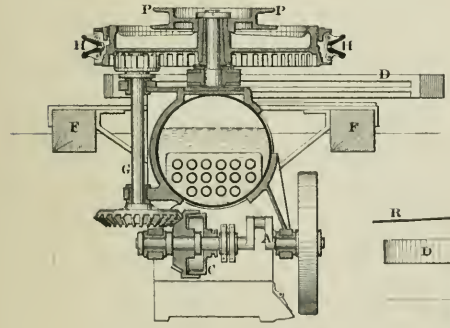
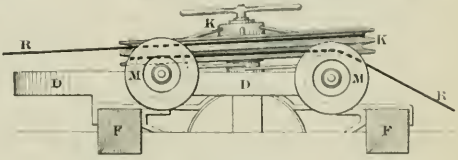



Fig. 20. *Leading Pulleys and Double-grooved Guide Pulley.*



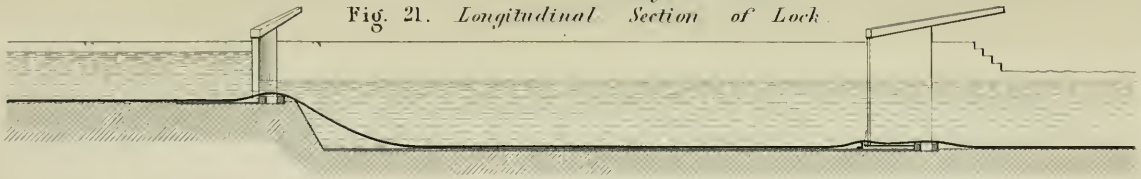

*(Proceedings Inst. M.E. 1869.)*

*Scale* $\frac{1}{40}$ *th*

0 1 2 3 4 5 6 7 8 9 10 *Feet.*

*Passage of Locks.*

Fig. 21. *Longitudinal Section of Lock.*



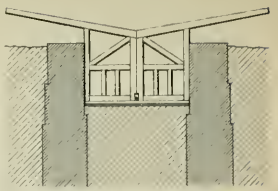


Fig. 23. *Transverse Section at upper end.*

Fig. 22. *Plan of Lock with single rope.*

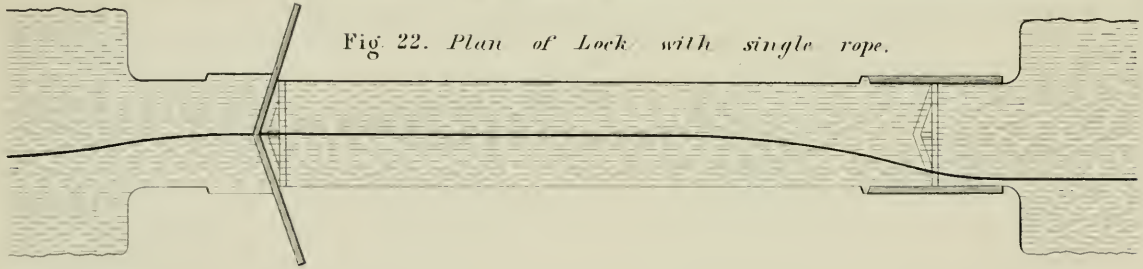


Fig. 24. *Plan of Lock with two ropes.*

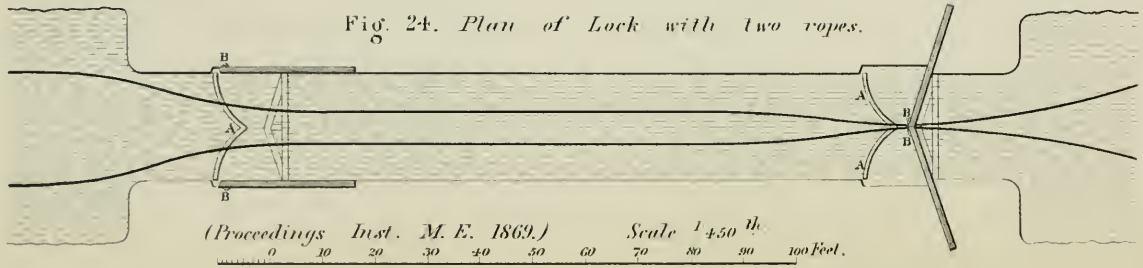
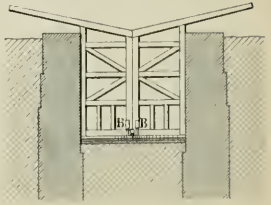



Fig. 25. *Transverse Section at lower end.*




*(Proceedings Inst. M. E. 1869.)* *Scale* $\frac{1}{450}$ *th*

0 10 20 30 40 50 60 70 80 90 100 Feet.

# WIRE-ROPE NAVIGATION.

*Passage of Tug round Curves.*



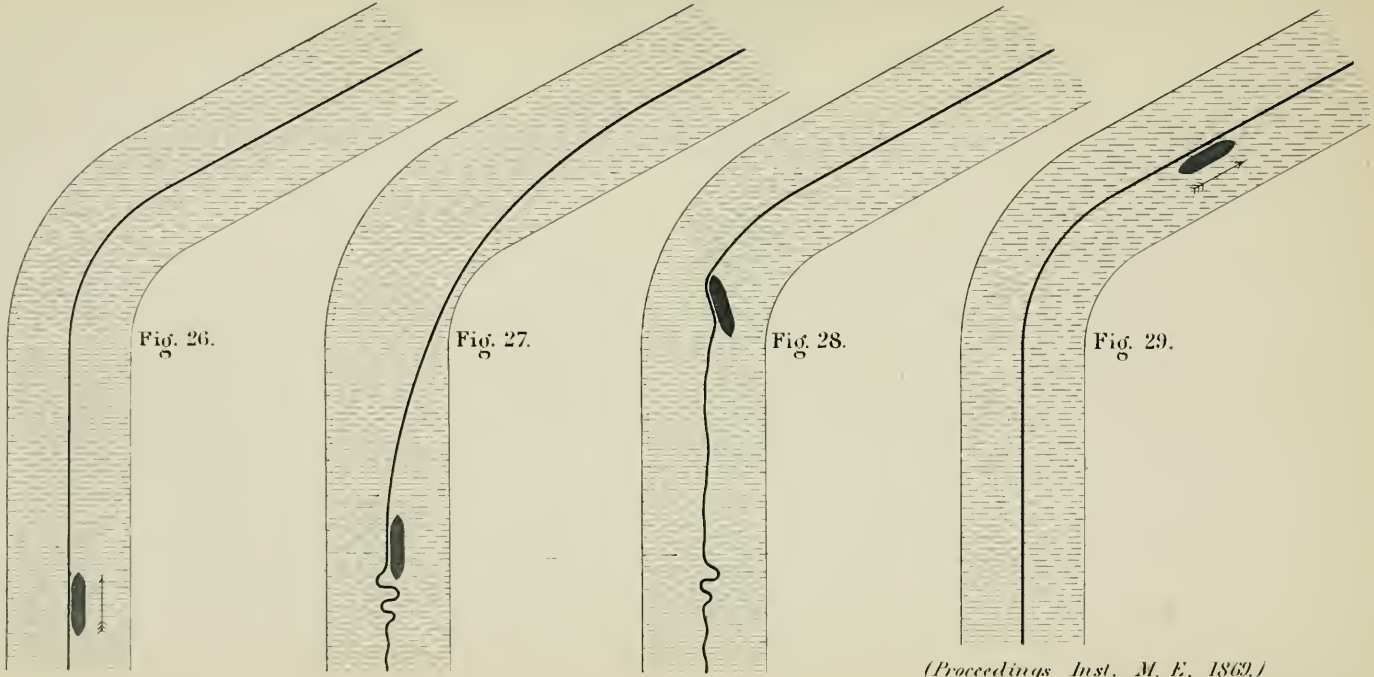


Fig. 26.

Fig. 27.

Fig. 28.

Fig. 29.

*(Proceedings Inst. M. E. 1869.)*

The Adjourned Meeting of the Members was held in the Lecture Theatre of the Literary and Philosophical Society, Newcastle-on-Tyne, on Wednesday, 4th August, 1869; Sir William G. Armstrong, President, in the Chair.

The following paper was read:—

# DESCRIPTION OF THE HYDRAULIC MACHINERY FOR WAREHOUSING GRAIN AT THE LIVERPOOL DOCKS.

By Mr. PERCY WESTMACOTT, of Elswick.

To supply a want that had for some time been felt in the port of Liverpool, there have recently been erected, in central positions on each side of the river, large handsome blocks of Warehouses fitted with mechanical appliances, designed by and executed under the supervision of Mr. Lyster, the Dock Engineer, for the stowing and conditioning of grain and breadstuffs. Although erected with this particular object, the warehouses have at the same time been so arranged and constructed that they can be converted into ordinary goods warehouses, and a large portion of the existing plant still left available. They are furnished with machinery for loading and discharging grain in bulk and in bags, casks and other merchandise, and also for transporting the grain into different parts of the building, and for ventilating the grain. The largest vessels can lie alongside, and have their cargoes either discharged direct upon the quay or conveyed to the top of the warehouses or to any floor. Proper accommodation for rail and road traffic is provided, and goods are discharged or loaded direct from or into wagons and carts. The warehouses on the Liverpool side are situated at the Waterloo Docks, and contain an aggregate amount of storage area of $11\frac{3}{4}$ acres, including the quay floor. Those on the Birkenhead side are erected on the margin of the Great Float, and have an area of 11 acres. The general mechanical appliances are similar in principle and construction at both warehouses.

The dock around which the blocks of warehouses on the Liverpool side of the river are situated, shown in the general plan, Fig. 1, Plate 46, is 570 feet long, 230 feet broad at one end, and

180 feet at the other. Three sides of the dock are occupied by separate blocks of warehouses, connected by wrought-iron bridges. The blocks on the east and west sides are 650 feet long and 70 feet wide, and that at the north end is the same width and 185 feet long. Each block contains five stories, as shown in the transverse section, Fig. 2, Plate 47: above the fifth or top storage floor and partly in the roof is placed the machinery floor; and below the quay level are wells and arched subways for the reception of the underground machinery. There are five discharging berths for large vessels, one at the north block, and two at each of the east and west blocks; and additional accommodation is provided for small vessels. In the centre or north block is placed the steam engine A, Fig. 1, of 370 horse power, which, in addition to driving the whole of the machinery in the warehouses, supplies power for working the lock machinery and the bridges over the entrances, consisting of two bridges of 60 feet span and one of 50 feet, twelve sluices, ten powerful ship capstans, and twenty-four machines for opening and closing the lock-gates.

From returns taken of the importation into Liverpool of the different descriptions of breadstuffs for the six years 1858 to 1863, it was estimated that these warehouses should be capable of working 250,000 tons per annum, irrespective of other ordinary merchandise; and from an average of the deliveries in Liverpool, it was estimated that two-thirds of the breadstuffs would arrive in bulk, and one-third in bags or casks. The chief importation is from America, and vessels coming from that continent, not being specially adapted for transporting grain in bulk, carry it in the hold, the other decks being laden with breadstuffs in sacks, bags, or casks, and with other kinds of merchandise. Moveable bulkheads or stiffenings are introduced into the hold fore and aft and athwart, to prevent the bulk of grain from listing or shifting its position, and also to keep different kinds or different consignments of grain apart when required. These bulkheads, and the general limited size of the hatchways, have hitherto interfered greatly with the facility for discharging cargoes of grain in bulk out of ocean-going vessels. The supplies of grain from France and elsewhere are generally

brought in bulk, but as yet no vessels are specially constructed for carrying grain in that manner; and until the example of the screw colliers for the conveyance of coal can be followed in this respect, it will not be possible to attain with the same ease the high rate of discharge of upwards of 150 tons per hour, which is arrived at in America in discharging grain out of specially arranged trading vessels.

The principal processes required to be performed by the machinery in the warehouses are the following. Discharging grain in bulk from vessels or small craft, direct on to the quay or into the warehouses. Hoisting grain in bags or casks from vessels on to the quay. Discharging ordinary merchandise direct on to the quay or on to any floor in the warehouses, and loading outward-bound vessels. Lifting and lowering sacks, bags, and other merchandise, on platform elevators and jiggers to or from any floor. Elevating, screening, weighing, and distributing grain in bulk, and conveying it to and from all parts of the warehouses and outwards for delivery into ships or wagons. Transferring grain from one part of the warehouses to any other part and back again, when required for the purpose of bringing into condition for market grain that is not suitable on account of dampness or heat.

In the extensive investigations and experiments that were conducted for the purpose of deciding the best means to be adopted for accomplishing these objects, particular attention was paid to the question of the kind of power to be used, and the most convenient, practical, and economical method of applying and distributing the power; and for this purpose trials were conducted with models and actual machines. Taking into consideration the number and variety of the machines required and the intermittent action and high speed of many of them—the great distances and the number of points to which the power had to be conveyed, not only in the warehouses but also to the bridges and lock machinery at the entrances from the river—the necessity of concentrating the motive power in one spot on the premises, so as to lessen the risk by fire and economise room and working expenses—the facility for augmenting the power at any

subsequent time—and the desirability of bringing no machinery into action except at the particular points where work is actually to be done—it was obvious that no system of motive power met these requirements collectively with so much effect, convenience, and economy, as the hydraulic system. The transmission of power by water pressure to the large block of corn warehouses at the Birkenhead Docks from the existing pumping engine in the tower at the northern entrances, a distance of 2300 feet or nearly half a mile, affords an excellent example of the ease, convenience, and economy with which hydraulic power can be conveyed to long distances, and past points that would prove greatly if not entirely obstructive to other methods. In this case the water pipes conveying the power pass from the engine house under three lock entrances, one of 100 feet width, one of 50 feet, and one of 30 feet width; and the power is transmitted without any appreciable loss.

The two accumulators, which generate the water pressure employed as the medium for conveying power to the whole of the machinery in the Liverpool corn warehouses and dock entrances, are situated at C C, Fig. 1, at each end of the centre or north block of building; and between the west block and the river entrances is placed a large auxiliary accumulator. The two accumulators in the north block are each weighted with a load of 70 tons, acting on a ram 17 inches diameter with a vertical range of 17 feet; and the auxiliary accumulator is loaded with 100 tons on a 20 inch ram having a range of 23 feet. The water pressure is conducted through cast-iron main pipes varying from 6 inches to 3 inches in diameter, and wrought-iron branch pipes convey the pressure from the mains to the several machines. In order to economise the consumption of water, which is obtained from the town supply, return pipes are laid to conduct the exhaust water from all the machines back again into a well in the engine house, from which the pumps draw their supply; and thus the same water is used over and over again. The steam engine charging the accumulators is situated on the quay level at A, Fig. 1, with its boilers B; it is a horizontal high-pressure engine with two steam cylinders, and the plungers of the double-acting force pumps are attached direct to the back of the pistons. The

engine is made in duplicate in all parts, to admit of either side being worked separately in case of need. Double-acting lift-pumps are provided for raising the supply and the return water from the storage well into a settling tank above the level of the engine, from which the forcing pumps draw their water. The engine is capable of forcing 209,350 cubic feet of water per minute against the accumulator pressure of 700 lbs. per square inch.

For the purpose of ascertaining the best means of conveying the grain horizontally from one part of the warehouses to another, a number of experiments were made with different plans. The common method of propelling grain horizontally by means of revolving screws was first tried, the experiments being conducted at a brewery fitted up with this class of machinery. The screw employed was 12 inches diameter and 4 inches pitch, made in lengths of about 12 feet from bearing to bearing; the space between the screw and the fixed casing in which it revolved was $\frac{1}{4}$ inch. At 60 revolutions per minute, which was found to be the maximum effective speed, this screw discharged the grain at the rate of $6\frac{3}{4}$ tons per hour, and required a power of 0·04 horse power for every foot run. The sectional area of the body of grain propelled by the screw was 49 per cent. of the whole transverse area of the screw. At a higher velocity than 60 revolutions the grain was simply carried round and not propelled forwards at all. With a subsequent screw of 12 inches diameter and 12 inches pitch, driven at 70 revolutions per minute, the most effective speed, 34 tons of grain per hour were discharged, and the power required to drive the screw was 0·125 horse power per foot run, or 37 per cent. less than in the case of the previous screw for the same delivery of grain. The sectional area of the body of grain in motion was 72 per cent. of the whole area of the screw. The saving in power in this case was owing to a better construction of parts, as well as to the quicker pitch. The effect upon the grain was very marked: with the previous screw the bulk was propelled without any appreciable agitation; whereas with the quick-pitched screw the grain was rubbed and polished and thereby improved in marketable condition.

In order to overcome the objections that were experienced with this screw, and to improve still further if possible the conditioning of the grain, trials were made with screws contained in revolving casings. Upon this principle a preliminary experiment was conducted with a 6 inch screw, 6 feet long, with 2 inch pitch and a depth of blade of $2\frac{1}{2}$ inches; a portion of the casing was perforated so as to act as a screen, which it did effectively. A second trial was then made with a 30 inch screw, calculated upon the result of the preliminary screw to discharge at the rate of 50 tons per hour. The length of this screw was 18 feet, and its pitch 12 inches or 2-5ths of the diameter. The body of the screw was properly balanced, and revolved upon finely adjusted rollers carried in cast-iron frames. A third experiment was also made with a 12 inch screw of 12 inch pitch, with the view only of ascertaining the effect of the quicker pitch. The results of these trials were as follows. The 6 inch screw discharged

| | | | |
|---|---|---|---|
| at | 60 | revolutions per minute, | 0·47 cubic foot of wheat per minute |
| ,, | 80 | ,, | 0·60 ,, |
| ,, | 100 | ,, | 0·50 ,, |
| ,, | 140 | ,, | 0·00 (no delivery) |

showing that, as the grain in this class of screw is propelled forwards by gravity, centrifugal force coming into action counteracts the effects of the discharge at high speeds. With the 30 inch screw a speed of 36 revolutions per minute was found to be the most effective. At this speed the grain was carried up on the rising side of the screw about 5 inches above the centre of the casing, and the discharge was $63\frac{1}{2}$ cubic feet or about 80 tons of wheat per hour, which was a much higher duty than had been calculated upon. The power required was 0·40 horse power per foot run; and the sectional area of the body of grain was 36 per cent. of the whole area of the casing. The 12 inch screw driven at the same speed of 36 revolutions per minute gave 10 tons of wheat per hour with a sectional area of only 17 per cent. The pitch of 2-5ths of the diameter proved the most effective of those tried. The manner in which these screws with revolving casings performed their work was highly advantageous to the grain, which became well rubbed and polished; and the revolving casing also obviated the principal objections experienced

with the previous fixed casing, which harboured dirt and caused the grain to be injured by the action of the screw blades revolving within it. The great power required to drive the screw with revolving casing became however an insuperable objection to its adoption upon a large scale.

The long distances through which grain had to be conveyed horizontally in the warehouses, amounting collectively to 7000 feet or about $1\frac{1}{3}$ mile, and the power that would be required for conveying it even with the best form of screw, rendered it expedient to seek some other mode of transport which would absorb less power; and recourse was finally had therefore to endless travelling bands. After a few preliminary trials with small canvas bands, experiments were made with a plain flat band 12 inches broad constructed of canvas and india-rubber. In order to obtain the greatest effect in this mode of conveying grain, the first point to be ascertained was the highest speed that could safely be attained with different kinds of grain. A speed of 8 feet per second was found to be the maximum for light oats and other light grain; and at this speed even bran and flour can be conveyed without any portion being blown off the band by the resistance of the air to its passage. A speed of about 9 feet per second can be accomplished with heavy clean grain, and a still higher speed with peas; chaff is blown off at about 9 feet per second. The quantity of grain discharged by the 12 inch band travelling at a speed of 8 feet per second was at the rate of about 35 tons per hour. Further trials were then made with a band 18 inches broad, formed of two plies of stout canvas covered with vulcanised india-rubber; this was the pattern subsequently adopted for permanent use. The band was made continuous, extending over a distance of 37 feet, and was supported upon plain cylindrical carrying rollers fixed at intervals of 6 feet apart, as shown at L L in Fig. 4, Plate 49. The rollers were made of wood, with wrought-iron spindles revolving in bearings of white metal and lubricated with hard grease. The band was driven by shafting, and provided with a self-acting tightening apparatus similar in construction to that finally adopted in the warehouses and shown in Fig. 4, consisting of a heavy tightening

pulley M suspended upon the band and sliding vertically between guides.

The maximum quantity of heavy grain conveyed by an 18 inch band is at the rate of about 70 tons per hour, and the power required to drive the band when fully loaded and delivering at that speed has been ascertained to be equal to about 0·014 horse power (1-70th h.p.) per foot run. The grain has no tendency to fall off the band, and indeed it is surprising to see separate grains, when placed close to the edge of the band, remain steadily in position whilst passing over the carrying rollers at the highest speed of working. Comparing the amount of power required to convey a stream of grain at the rate of 50 tons per hour through a distance of 100 feet by means of the common screw in stationary casing, the tubular screw with revolving casing, and the travelling band 18 inches wide, the following are the results that have been obtained :—

| | | |
|---|---|---|
| With the common screw | . . . . | 18·38 horse power. |
| „ tubular screw | . . . . | 25·00 „ |
| „ 18 inch travelling band | . . . | 1·02 „ |

showing the great superiority of the band over the screws in economy of power.

For the purpose of passing the grain off on either side of the main travelling bands and at any points along their course, several contrivances with air-blast and brushes driven from the band itself were tried, but with indifferent success: both methods were objectionable on account of raising dust, and the friction of the brushes proved injurious to the band in course of time. The idea then occurred of diverting the stream of grain by means of an upward deflection of the carrying band, thus casting the grain clear from the band into the air for a short distance, so that it could then in falling be caught and led off by a spout to either side as required. This arrangement proved thoroughly successful, and has been extensively adopted in practice in connection with the use of the endless travelling bands for carrying grain. The "throwing-off" apparatus is shown in Figs. 6 and 7, Plate 50, and consists of a couple of wrought-iron rollers B B, centred in gun-metal bearings in a rocking frame C, which is hung in a moveable carriage D running upon the timbers E of the

wooden framing that supports the travelling band II; the carriage is moved to any position along the length of the band where the grain is required to be discharged, and is there secured by the wedges F F and the clamping screw G. The rocking frame C is rotated in either direction by means of the screw and wormwheel H, so as to bring the pair of rollers B B into action in the proper position for throwing the grain off in the same direction in which the band I is running; and the rollers are turned back into the horizontal position so as to be clear of the band when the carriage D is required to be moved to another place along the band. A curved spout K, Fig. 7, is attached to the carriage D for catching the stream of grain in its fall and leading it off on either side of the band I. No difficulty is experienced in keeping the grain on the band; but it is found necessary to glide the grain upon it from the feeding hopper through a spout rather less than half the breadth of the band, and set at an inclination of $42\frac{1}{2}$ degrees to the horizontal, so as to give the grain falling upon the band a horizontal velocity nearly equal to that of the band. Some difficulty has however been experienced with this and other portions of the machinery from the fine dust and grit thrown off with the grain, and it has been necessary for the machinery to be protected from injury at these places. As the flow by gravity of various kinds and conditions of grain through the spout from the hopper varies considerably, it is found necessary to place a pair of oblique side rollers at the point where the grain falls upon the band, in order to curve the band into a slightly hollow form at this point and thereby prevent the tendency of the grain to spread. In passing heavy quantities of grain along the bands to great distances it has also been found expedient to apply at intervals pairs of these oblique side rollers, which are carried in moveable frames that can be set at any required spot.

The cross bands J J, Fig. 4, for conveying the current of grain in a direction at right angles to the main bands, are driven from the lower or return half of the main band, which is passed half round a driving roller R at each of the cross bands; and the motion is communicated from this roller to the cross band through a pair of mitre wheels S, Fig. 5, with a clutch T for throwing the driving shaft in or out of gear. The cross bands, or other machinery such as the centrifugal

distributing fan, can also be driven by simply depressing the return half of the main band by means of a roller carried in a rocking frame, sufficiently to bring the band well into contact with a fixed roller situated underneath, which being then driven by the main band can communicate the required motion for any purpose; and this simple mode of taking off power from the main bands has proved of service in many ways.

In order to save labour in spreading the grain over the floors of the warehouses, and also for the purpose of ventilating it and improving its condition, a revolving fan for scattering the grain was tried with success, as shown at N in Figs. 2 and 3. This fan, shown to a larger scale in Figs. 8 and 9, Plate 51, is carried upon an upright shaft driven from the main band by the same arrangement as that described for driving the cross bands. As the band is required to travel sometimes in one direction and sometimes in the opposite, the fan had to be made with straight radial vanes, Fig. 9, to allow of its revolving in either direction. The grain is led by a spout on to the top of the fan, Fig. 3; and to avoid the separation of heavy and light particles in the mass and to spread the grain as evenly over the floor as possible, a conical form is given to the body of the distributing fan, as shown in Fig. 8, and the alternate blades are made of a different length and shape, as shown on the two sides of Fig. 8. By means of a hinged tongue placed in the end of the delivery spout above the fan, the discharge of the grain is directed to any particular spot by turning the tongue round into the required position. The fan is placed $9\frac{1}{2}$ feet above the ground, and at its usual speed of 250 revolutions per minute it deposits the grain in a circle of 45 feet diameter.

Five hydraulic cranes for discharging vessels are fixed in towers specially constructed in the warehouses, as shown at O in Fig. 2, Plate 47. These cranes are arranged for raising grain in tubs containing 21 cwts. of bulk, at a maximum rate of 50 tons per hour under the most favourable conditions; and they are also employed for landing sacks, casks, and other merchandise on to the quay or to any of the warehouse floors. The lifting chain has an extreme range of

130 feet, and the jib an extreme projection of 24 feet beyond the quay; a traversing motion of $7\frac{1}{2}$ feet is given to the foot of the jib, as shown in Fig. 2, but this is only required to be brought into play for the largest class of vessels. The motions are all effected by hydraulic power under the control of one man stationed on a platform in the tower. The grain is filled into the tubs in the hold of the vessels; and there has been difficulty in getting a right form of tub to suit all the conditions under which the work has to be done. The first form of tub employed was the ordinary tipping tub, which has by long experience been found to answer best for the discharge of coal, salt, and gravel, &c. The next form tried was a tub that required no tipping, but was fitted with a cone to deliver the grain through the bottom. The form that proved on the whole most satisfactory requires also no tipping, and is fitted with a butterfly valve in the bottom; when this tub is in position for emptying into the upper receiving hopper P, Fig. 2, the valve is opened by a lever from the platform on which the man is stationed to work the crane. The time occupied by this form of tub in emptying itself shows a wide difference in the rapidity of flow of various sorts of grain: with wheat in good and dry condition the tub empties itself in 5 seconds, with barley in 7 seconds, and with indian corn in from 9 to 10 seconds.

The hopper P, Fig. 2, into which the grain lifted by the crane to the top of the warehouse is dropped from the tub, holds about 8 tons of grain; and from this hopper the grain is diverted into two streams, and allowed to flow through spouts fitted with regulators on to two 18 inch inclined bands Q, Figs. 2 and 3, driven by one hydraulic engine. One of these bands would be sufficient to carry the grain delivered by the crane, but two are employed in order to spread the grain out more, and facilitate the separation of the dust from the grain when required; the separation is simply effected by an inclined flap fixed in the inner receiving hopper R, Figs. 2 and 3, into which the two bands Q convey the grain from the outer hopper P. From the inner hopper R the grain is allowed to drop through a valve into a 1 ton weighing hopper S; after which it is delivered, by a simple arrangement of doors in the bottom of the weighing hopper, on to

either side of the distributing hopper T, from whence it passes on to one or other of the 18 inch bands I I which traverse the entire length of the warehouses. One man stationed at the weighing machine S regulates the flow of grain from the several hoppers, and records the quantity passed.

Two main lines of 18 inch bands, made to run in either direction, are necessary for the convenient working of these warehouses. A vessel for instance lying at a berth at the west block of the warehouses may require its cargo deposited at either end of that block or at any spot in either of the two other blocks; and at the same time another vessel lying at the east block opposite may have its cargo housed in the west block. Thus it often happens that two full streams of grain are flowing in opposite directions, and that a current of grain is carried right round the warehouses. The bands in the east and west block are divided into two lengths, and those connecting these two blocks and passing through the north block are in one length. Each band is fitted with a separate tightening-up apparatus, as shown at M, Fig. 4, and is driven by a separate hydraulic engine N of about 3 horse power, having two cylinders and fitted with reversing and regulating gear which can be controlled from any point along the entire length of the band. At each point where the flow of the grain has to be diverted from one band to a cross band, a fixed throwing-off carriage is stationed. Two moveable throwing-off carriages are provided on each main band, for casting the grain off the band into the wooden descending spouts $8\frac{1}{2}$ inches square, which convey the grain from the top of the warehouse and deposit it on any floor in the building. There are 56 of these spouts U U, Figs. 2 and 3, passing from the upper machinery floor down to the lower 12 inch bands in the arched subways V V below the quay level, Fig. 2; and they are provided with sliding doors at the different floor levels to admit of the grain being shovelled into wagons standing on the railway which traverses the centre of the block, or on to the lower 12 inch bands for conveyance to the elevators. A number of other shoots at suitable intervals are built in the walls of the warehouses fronting the dock at the levels of the several floors, and are each provided at the first floor with a delivery

outlet, to which a moveable spout is hooked on for delivering grain from the warehouse into vessels. The arrangement of the lower band machinery is a counterpart of the upper, but upon a smaller scale and without the moveable throwing-off carriages provided on the upper bands, which are not required for the lower. These lower bands are employed for the purpose of conveying grain from any one of the descending spouts to any one of the five elevators W, Fig. 2, which are fixed in the crane towers. The grain conveyed along these 12 inch main bands is thrown upon the 18 inch cross bands, which deliver it into the hopper X supplying the elevator W; one 18 inch cross band will carry the full quantity of grain conveyed by the two 12 inch bands, and the cross bands are arranged to receive their motion from either line of the main bands. Much of the grain discharged from the vessels in the dock is sorted upon the quay, and is then thrown by hand into the hoppers X of the elevators.

The construction of the elevators W, Fig. 2, for raising the grain from the bottom to the top of the warehouses, is shown to a larger scale in Figs. 10 to 12, Plate 52. The wrought-iron bucket W, capable of containing about 21 cwts. of grain, is slung from the lifting chain by an arrangement of bars and levers, and provided with guiding rollers running between upright timbers, which are so arranged that on arriving at the top the bucket tips over, as shown in Fig. 10, and discharges the grain into the top hopper Y; this hopper delivers the grain upon the same inclined cross bands Q, Fig. 2, that convey the grain from the outer crane hopper P. The bottom hopper X supplying the elevator, Fig. 11, is made in two parts, the upper of which, protected by a grating, receives the bulk of the grain, while the lower compartment Z contains only one charge at a time for the elevator bucket W, and is separated from the upper portion X by a sliding valve. In descending, the bucket having had its speed checked on approaching the bottom strikes the arm of a tappet lever A, Fig. 11, which closes the valve between the two compartments X and Z of the hopper; and continuing its descent still more slowly the bucket strikes another tappet arm B, which disengages the iron flap C that covers the front of the lower

compartment Z; this flap falling forwards by the weight of the grain behind it acts as a shoot for delivering the grain from the lower hopper Z into the bucket W. As soon as the bucket has received its charge, the motion is reversed for lifting. In beginning to ascend at a moderate speed the bucket again closes the flap C of the lower hopper, which is held up against the hopper as shown dotted in Fig. 11 by means of spring catches D D; and the bucket then strikes the tappet lever A of the hopper valve, and reopens the communication between the two compartments X and Z of the hopper. The speed is then accelerated until the bucket arrives within a short distance of the top receiving hopper Y, Fig. 10, when the speed is again retarded before the grain is shot out. The motion of the bucket is regulated by means of self-acting gear. These bucket elevators are intended to raise the grain at a rate of about 50 tons per hour, but they are capable of being worked at a higher speed. The chain of the crane O, Fig. 2, is employed for lifting the bucket of the elevator, the same chain being applied to the crane or the elevator according to the requirements of the work; but it has lately been found expedient, on account of the demands of the traffic, to make the elevators independent of the cranes; and for this purpose separate hydraulic cylinders with their adjuncts are now being supplied for working the elevators.

Trials have been made for lifting grain by means of dredging machines, and it has been found that with a dredger 30 feet long 50 per cent. of the applied power proved effective. Experiments are also in progress for raising corn by air pressure or suction, and the results already obtained are sufficient to prove that this system possesses advantages over the other plans in use; it is however at the same time surrounded with difficulties and obstructions, which must be removed before it can be employed with advantage upon a large scale.

Casks, bags, and other merchandise are raised or lowered either by hydraulic cradle hoists or by jiggers. There are twelve of the hydraulic hoists of the ordinary construction, each capable of lifting a load of 1 ton to the uppermost floor of the warehouses; and they are found serviceable also in assisting to break out the cargoes from the fore and aft hatchways of a vessel lying with its centre hatch in

line with the crane or elevator; for this purpose the lifting chain is disconnected from the cradle of the hoist, and led through a snatch block to the rigging of the vessel. The twenty single-acting outside jiggers, originally constructed only for lowering loads by friction, have recently been supplied with auxiliary hydraulic power for lifting loads of 6 or 7 cwts. Twelve double-acting jiggers for loads up to 10 cwts. have recently been added in the centre of the blocks of warehouses, for lifting and lowering goods to and from railway wagons; they are so constructed that they may be used either singly or in conjunction, either for lifting or lowering. Thus both machines may be alternately lowering goods down into wagons below from any of the floors of the warehouses, or by means of the water pressure they may both be raising goods from the wagons to any of the floors; or one side of the machine may be lowering whilst the other is hoisting goods from the hatchways of vessels to which the lifting chain is capable of being led.

In conclusion it may be remarked that one of the great advantages attending the adoption of hydraulic power for the work to be performed in these corn warehouses consists in the facility afforded by this system for the future extension of the power to any point where additional contrivances may be required for saving time and hand labour.

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Mr. Ramsbottom observed that the corn warehousing machinery described in the paper just read was an excellent illustration of what could be done by hydraulic machinery in an entirely new application; and the numerous details involved in that arrangement for transporting large quantities of grain appeared to have been admirably carried out for the accomplishment of the object in view. He enquired how long the machinery had now been at work at the Liverpool docks, and what had been found to be the result as regarded the wear of the travelling bands carrying the grain.

Mr. Westmacott replied that the machinery had now been more than a year at work, and the bands had proved completely satisfactory in working. Their durability would have to be decided by experience: they had done a large amount of work in carrying grain, without any failure and without showing any appearance of wear so far.

Mr. J. Fernie mentioned that in the storing of barley in a brewery warehouse at Burton-on-Trent he understood the grain had been damaged in transporting it from one room to another by mechanical means, in consequence of the ends of the grains of barley getting broken off, which prevented the grain from sprouting and injured it for malting purposes; and he enquired whether any such objection had been experienced in the use of the travelling bands for carrying the grain in the manner described in the paper.

Mr. Westmacott said that in the instance referred to at Burton-on-Trent the transporting of the grain was performed by means of a screw, the blades of which were found to have the injurious effect described; and this had been one of the reasons for adopting the plan of travelling bands for carrying the grain in the machinery at Liverpool. No injury whatever was done to the grain by this mode of carrying, as it flowed direct from a hopper on to the travelling band, and glided upon the band at the same velocity at which the band was travelling, and was then conveyed by the band to the required distance, without meeting with any obstruction at any part of its course.

Mr. G. Gilroy mentioned that at the Ince Hall Collieries near Wigan he employed the same principle of a travelling band for carrying the slack and small coal away from underneath the coal screens, and had now had it at work for nearly a year. The band was driven in this case by a steam engine, and passed transversely underneath the whole range of coal screens; it was inclined at an angle of from 25° to 35° to the horizontal, for raising the slack up to the required level, and there was no difficulty in carrying the slack at a considerably greater inclination for a short distance of a few yards only. The band was 20 inches wide, made of sacking canvas, and was carried over wooden rollers, with driving

drums 20 inches diameter at the two extremities of its travel. This plan had been found to answer very well, instead of the heavy machinery usually employed for such purposes; and the expense was very trifling in comparison.

Mr. E. H. Carbutt mentioned that he had seen a long travelling band in use at the Crewe Works for carrying the sawdust and shavings from the wood-working machinery direct to the boiler house to be used for raising steam.

Mr. Ramsbottom said he had first adopted the use of a travelling band at Wolverton three years ago, where the whole of the refuse from the circular saws and other wood machines was swept up and conveyed on a long endless band to the boiler house to be used for firing the boilers. The band lay at the bottom of a wooden trough, into which the waste stuff was delivered from the machines; and this plan had been found to work exceedingly well, with very little friction of the band in the trough. Without the trough the stuff would more or less fall off the band; and he enquired whether in the corn warehousing machinery described in the paper the travelling band was carried in a trough or on any sort of slight wooden flooring.

Mr. Westmacott replied that no trough was employed for the bands carrying the grain, which were perfectly flat and were carried only upon plain cylindrical rollers placed horizontally at intervals of 6 feet.

Mr. F. J. Bramwell remarked that, having been connected some years ago with the erection of the City Corn Mills in London, working 32 pairs of stones and containing about a million cubic feet of space, he could appreciate the difficulties attending the warehousing of such large quantities of grain as had been mentioned in the paper, and also the complete manner in which those difficulties appeared to have been overcome by the arrangements described. The conveyance of grain by screws working in non-revolving troughs certainly required a considerable amount of power, but not nearly so much as the power needed when the trough or casing revolved with the screw. For milling purposes, as the grain was about to be ground, there was not the objection to the rubbing off of the ends, which there was when the grain was going to be malted; indeed in a corn mill

the rubbing together of the grains was a desirable process, for it helped to get rid of extraneous matter; and with this object of cleaning the grain in the act of its transportation he had used a screw fixed inside a cylindrical woven wire casing, the screw and casing revolving together. By driving the screw at a considerable speed, but not so fast as to keep the grain against the circumference of the cylinder by the centrifugal force due to the speed of revolution, the grain was caused to climb up one side of the cylinder and then to fall over to the bottom. As the cylinder revolved and the grain moved forwards, the dust and small particles escaped through the woven wire into an outer case, along which they were caused to travel by a separate small screw. With the use of this apparatus the grain was much improved in condition for grinding, but the consumption of power was considerable, and such a mode of moving would therefore not be suitable where the grain had only to be warehoused. An extremely simple method employed in the French mills for conveying meal or flour consisted in the use of a revolving wooden shaft carrying a series of little wooden pallets like small spades arranged in a spiral around it, and set inclined so as to form practically segments of a screw. The pneumatic system of lifting grain, to which allusion had been made in the paper, had now been in use for many years in thrashing machines, a large number of which were fitted with blowing fans producing a considerable blast, whereby the grain was blown into the upper part of the machine, instead of being lifted by the elevators previously employed; and the substitution of the fan was found to be attended with considerable advantage to the quality of the grain. The employment of endless travelling bands however, as described in the paper, appeared to him to have an important advantage over the previous modes of transporting grain, because the grain was there conveyed with the least possible amount of motion amongst the particles, and consequently with the least possible injury to the material itself by rubbing. Any motion of the particles of grain upon the apparatus by which they were conveyed, as in the case of a screw and trough where the particles had a sliding motion along the trough, must be attended with an absorption of power;

and a still greater absorption of power must be occasioned by the motion of the multitude of particles rubbing against one another; and it was therefore clear that the mode of transport by conveying the grain in a quiescent state upon a travelling band must be a most economical one as regarded power, inasmuch as there was no motion whatever either between the grain and the band on which it lay or between the particles of the grain itself. He was much struck with the very ingenious arrangement for transferring the grain from one band to another, throwing it off the band on either side by the simple contrivance of elevating the band at the required place by means of the moveable carriage, which could be adjusted at any point desired along the course of the band. With regard to the mode of raising the grain out of the hold of a vessel, he enquired what was the reason for employing a bucket for this purpose in preference to the dredging elevator which was largely used in America for that work; he should have thought the dredging system would have been found more expedient, on account of the extra labour involved in filling a bucket.

Mr. Westmacott said that the corn warehouses at the Liverpool docks had been constructed to serve for ordinary merchandise hereafter, if found expedient; and as the vessels which carried grain, particularly those from America, were not specially constructed for carrying it in bulk, and were laden on the upper decks with ordinary merchandise, it was considered advisable to introduce the crane system, which would be applicable for mixed cargoes. Subsequently to the opening of the warehouses, an elevator had indeed been provided for unloading barges and the smaller sized vessels.

With regard to the power required for transporting grain by screws and by travelling bands, he had found by experiments that in conveying it at the rate of 50 tons per hour through a horizontal distance of 100 feet it took between 18 and 19 horse power with a common screw revolving in a fixed case, and 25 horse power with a screw working in a revolving case, whilst the travelling band 18 inches wide required only 1 horse power for the same work.

Mr. E. A. Cowper enquired what was the mode of communicating the driving power from the main band to any one of the transverse bands.

Mr. Westmacott replied that at each of the cross bands the lower or return half of the main band was passed half round a driving roller, from which the motion was communicated to the cross band through a pair of mitre wheels, with a clutch for throwing the driving shaft in or out of gear.

Mr. J. Kennan enquired what was the maximum inclination of the band carrying the grain, at the points where it was elevated for throwing the grain off the band; and whether the extent of inclination up which the grain could be carried was affected by the velocity at which it was conveyed by the band; and also whether the grain was at all disturbed on the band when it came to those places, in consequence of the increased inclination.

Mr. Westmacott said he had not made an actual trial of the maximum inclination at which the grain could be carried by the bands without being disturbed, but he had run it up at a high angle and believed the inclination would not be far short of 40° at the point of throwing the grain off; he had not ascertained whether the speed of the band made any difference in the inclination at which the grain could be run up. Peas, if carried in a thick stream, could be run up a steep inclination; but if carried in a thin layer on the band, they would run back unless the inclination of the band was made less steep than for grain. Near the point of throwing the grain off the band, as well as at the place where it was delivered upon the band from the spout, it was found advisable to provide a pair of oblique side rollers, to curve the edges of the band slightly upwards, thereby collecting the grain more towards the centre of the band. This precaution also obviated any difficulty that might otherwise be occasioned by the carrying rollers getting out of truth; and a pair of oblique side rollers planted on a portable frame could readily be applied at any place where a tendency was found for the grain to run off the band.

Mr. R. Mallet observed that, if the angle of repose of grain was about 35°, it probably would not be practicable to carry up the

grain upon a band inclined at a steeper angle. If it were necessary in any case to run the band at an inclination steeper than that limit, he suggested that possibly the grain might be prevented from running back by fixing small strips of wood transversely or diagonally across the upper surface of the band at short intervals.

Mr. WESTMACOTT said the objection to any transverse strips projecting on the upper surface of the band was that they would catch against the extremities of the spouts delivering the grain upon the band, the bottom edge of the spout being at present brought down close upon the surface of the band, so as to deliver the grain upon the band with the least amount of drop; and the uniformity of the layer of grain deposited upon the band would be disturbed by any inequalities on the surface of the band.

Mr. L. OLRICK mentioned that, in the event of the hydraulic apparatus being called into requisition at any time for extinguishing a fire in these corn warehouses, the "Field" boilers supplying the steam for working the engine that charged the accumulator had the advantage of being able, on account of the small quantity of water contained in proportion to the heating surface, to get up steam from cold water in 20 minutes to 10 lbs. pressure, which was sufficient for starting the engine, and to 50 lbs. pressure in 30 minutes; whereas with a Cornish boiler about an hour would be necessary for raising steam from cold water to the first pressure; and the five 60 horse power boilers which were employed in this instance did not occupy more floor space than one 30 horse power Cornish boiler of ordinary construction.

The PRESIDENT moved a vote of thanks to Mr. Westmacott for his paper, which was passed.

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The following paper was then read:—

# DESCRIPTION OF A REVOLVING FURNACE FOR CHEMICAL WORKS.

By Mr. R. CALVERT CLAPHAM and Mr. HENRY C. ALLHUSEN, of Newcastle.

The conversion of Sulphate of Soda into Crude or Ball Soda is the third process conducted in alkali works; and its importance will be understood from the statement that in the Tyne district alone, 455,000 tons and £560,000 represent the total annual quantity and value of the sulphate of soda, chalk, and coal, operated upon in reverberatory and revolving ball furnaces. The Revolving Furnace was introduced in 1853 by Messrs. George Elliott and William Russell, with the object of effecting by machinery that which from 1794 had been accomplished by hand labour; but owing to the numerous practical difficulties encountered, the economy and other advantages expected were not realised, and no extensive application of the revolving furnace would yet have taken place, had it not been for the perseverance of Messrs. Stevenson and Williamson of the Jarrow Chemical Works, who made improvements on the original plan, and erected five of the fifteen revolving furnaces that are now working in England.

In this description of furnace the charge of material to be acted upon is placed in a revolving cylinder A, shown in the general longitudinal section, Fig. 1, Plate 53, and to a larger scale in the longitudinal and transverse sections, Figs. 2 to 4, Plates 54 to 56. This cylinder is constructed of 5-16ths inch boiler-plate lined with firebricks, and is mounted so as to allow the heat from the firing furnace B at one end of the cylinder to pass conveniently through it and over the liquid contained in the evaporating pan C at the other end, Fig. 1. In exterior measurement the cylinder is 15 ft. 6 ins. long and 9 feet diameter; and its interior measurement is 13 ft. 3 ins. length, 7 ft. 6 ins. diameter in the centre, and 6 ft. 6 ins. diameter

at either end. In the brick lining are fixed two rows of fireclay blocks DD, Figs. 3 and 4, termed "breakers," which stand 14 inches above the lining in the centre and 9 inches at the ends: by these breakers the contents of the cylinder are thoroughly mixed and successively exposed to the fire. Between the firing furnace B and the cylinder A a loose collar E is adjusted, Figs. 1 and 2, which consists of a wrought-iron hoop lined with firebricks; and between the cylinder and the evaporating pan C at the other end a space F is left, termed the "smoke-chamber," so that the greater portion of the particles carried forwards by the strong draught may be deposited there, instead of in the liquid to be evaporated. In the downcast at the extremity of the pan C a main horizontal damper G is secured by a chain, so that no more than the requisite draught can be obtained; and further control over the draught is given by a vertical damper H placed between the pan and the downcast, and counterbalanced by a weight suspended near the engine.

The mechanical apparatus for rotating the revolving cylinder, as shown in Figs. 2 to 4, Plates 54 to 56, rests on a bed-plate $2\frac{1}{2}$ inches thick, which is cast in five pieces fastened together by six wrought-iron hoops shrunk on, the whole being secured to the stone foundation by twelve $1\frac{1}{2}$ inch bolts. The vertical direct-acting engine K, Fig. 4, with reversing link motion, has an inverted cylinder 9 inches diameter and 12 inches stroke, working at 6 horse power with 30 lbs. pressure. The cylinder A of the furnace makes one revolution per minute when in the quick motion, and one revolution per five minutes when in the slow motion. The quick motion is obtained direct from the crank through the upper line of shafting L L, upon the end of which is a worm I working into a large wormwheel J J fixed round the pan end of the revolving cylinder by means of feet and screw bolts. In some cases this wormwheel has been cast in segments; but on account of their inaccuracy and the difficulty experienced in getting the pitch of the teeth correct at the joints, a single casting is deemed preferable. The slow motion is obtained by disengaging the friction cone M on the upper shaft L, and putting into gear the lower shaft N, so that the spur-wheel and pinion at either end of the lower shaft N work into the pinion and spur-wheel on the upper shaft L.

The revolving cylinder A is carried upon two pairs of cast-iron flanged bearing wheels P P, Figs. 2 and 3, with $4\frac{1}{2}$ inch axles supported on diagonal carriages. The bearing surfaces of the cylinder are two cast-iron rings Q Q rivetted round its circumference, and each strengthened by two wrought-iron hoops $1\frac{1}{2}$ inch square. Each ring is faced with a wrought-iron tyre, secured by countersunk bolts, and in some instances the tyres have been shrunk on in one piece, after boring them out and turning the rings; but the expansion from the pressure and heat sooner or later cause the tyres to roll out and become loose, and consequently to snap the bolts. For this reason it is found advisable to fix the wrought-iron tyre in segments, with diagonal face joints, and to have the countersunk bolts passed through oblong holes in the cast-iron ring, by which means expansion is allowed for and the breaking of the bolts prevented.

The charge for the revolving furnace at the Tyne Chemical Works consists of

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|---|---|
| Sulphate of Soda . . . . | 22 cwts. |
| Chalk . . . . . | 25 „ |
| Coal . . . . . | 12 „ |

The sulphate of soda falls through a $\frac{1}{2}$ inch screen, as delivered into the depot, and thus an adequate quantity of fine material is secured for the cylinder without expense; the chalk is charged into the cylinder in moderate sized blocks, whilst the coal is divided, 3 cwts. being mixed with the sulphate and 9 cwts. with the chalk. On the day-shift, during which the evaporating pan is drawn, five charges are worked, and on the night-shift six, the full work being six days at 12 tons 2 cwts. of sulphate of soda per 24 hours, making 72 tons 12 cwts. per week. The method of proceeding is as follows:—in the first place the 25 cwts. of chalk and 9 cwts. of coal are charged, and the cylinder is made to revolve with the slow motion. After the expiration of 1 hr. 10 mins. the "liming" or conversion of the chalk into lime is generally effected, and its completion is always indicated by a bluish flame round the charging door; the 22 cwts. of sulphate and 3 cwts. of coal are then added, and the vertical damper H, Fig. 1, is lowered for ten minutes, so as to give the smallest possible amount of draught. In about twenty minutes after the damper has been raised

again, the fluxing of the sulphate becomes apparent by the escape of a bright yellow flame round the charging door, and the motion of the cylinder is then changed at once from slow to quick. A small door R in the arch over the pan C, Fig. 1, enables the workman to ascertain when the decomposition of the materials is sufficiently advanced, of which he judges by their clear colour and increasing consistency, and also by the light yellow jets of flame that issue from portions of the fluxed mass adhering to the breakers in the cylinder. This stage is usually attained in half an hour, and the contents of the cylinder are then run out, the total time expended on the whole operation amounting on the average to 2 hrs. 10 mins.

In comparing the working of the revolving furnace with that of the ordinary hand furnaces, it must be borne in mind that any such comparison is affected by a variety of local circumstances; and the results given in the present paper have principally been deduced from observations made and abstracts taken at the Tyne Chemical Works, where there are twenty-five hand furnaces and two of the revolving furnaces, and all the materials charged are elevated by means of a wagon and lift.

The cost of construction of a revolving furnace may be estimated at about £1500, exclusive of the charging machinery, and the building containing the furnace would cost about £500 per furnace, making the total cost of the furnace about £2000. A hand furnace costs about £325, and its containing building about £175, making £500 total. The expenditure involved in crushing and elevating the materials may be considered equal in the two cases; but the revolving furnace requires steam for its engine and liquor pump, and a proportionately stronger draught, thus necessitating a greater outlay on the boiler, flue, and chimney. When in thorough order a revolving furnace can ball 72 tons 12 cwts. of sulphate of soda per week of six days, and a hand furnace 21 tons 12 cwts.; but taking into account stoppages for repairs, the former does not exceed 66 tons per week whilst the latter accomplishes 21 tons.

The consumption of coal, including firing, heating up, chalk-drying, and raising steam, is less in the revolving furnace than in

the hand furnace, and with some qualities of coal the difference has been found to be 1·5 cwts. per ton of sulphate balled, the consumption being 10·7 cwts. per ton of sulphate in the revolving furnace against 12·2 cwts. in the reverberatory furnace. The reverberatory furnace requires dry and ground chalk, and half of the chalk used in it is dried in kilns, and is then ground in a mill with the remaining half wheeled direct from the depot; but the revolving furnace can be charged with damp and rough chalk, and the whole of the chalk supplied to it is used without drying or grinding. An advantage is thus afforded to the revolving furnace of 6*d*. per ton on the sulphate balled, which however has thus far been seriously reduced by the difference in cost of repairs, the account for repairs from September 1867 to June 1869 showing 1*s*. 3*d*. per ton of sulphate in the revolving furnace against 10*d*. in the hand furnace. The rate paid for charging the furnaces is identical; but in working them there is a distinct saving in wages with the revolving furnace of 1*s*. per ton of sulphate, the present cost of working being 2*s*. 6*d*. per ton of sulphate in the hand furnaces and 1*s*. 6*d*. in the revolving furnace, inclusive of heating up.

The chemical results are slightly in favour of the revolving furnace, so far as the quantity and strength of the alkali produced are concerned, especially where causticity is required; but in the works where chalk is used instead of limestone, the carbonate of lime carried over by the draught into the evaporating pan is found to render the salt drawn out not so well adapted to the manufacture of crystals of soda as that taken from the hand-furnace drainer.

Although in the majority of alkali works where the revolving furnace has been adopted, the opinion obtains that in addition to general superiority over the reverberatory furnace it also presents an evident advantage during wages disputes, yet there are sufficient grounds for stating that obstacles still exist which must be modified, if not removed, before the old furnace can be entirely superseded by the new one. Improvements in the latter are clearly required for reducing the consumption of coal and the cost of repairs, and for increasing the quantity of sulphate balled and improving the quality of carbonate produced; and in referring in the present paper to the

difficulties hitherto experienced, it is hoped that by the attention directed to them they may more speedily be overcome.

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The PRESIDENT enquired how long the two revolving furnaces had now been in use at the Tyne Chemical Works.

Mr. HENRY C. ALLHUSEN replied that they had now been at work for two years, and in continuous operation during the whole of that time, excepting when standing for repairs.

Mr. I. LOWTHIAN BELL said he had one of these revolving furnaces in use at the Washington Chemical Works, and as the substitution of machinery for manual labour was undoubtedly a matter of importance, it must be admitted that to this extent the revolving furnace did certainly possess considerable value; but in respect to the results obtained, both economically and chemically, it had not proved hitherto so satisfactory as had been hoped. The chemical reactions taking place in the process of balling soda were of so complicated a nature, that he thought the degree of regularity in the products obtained from the ordinary furnaces worked by hand was surprising, notwithstanding that it still fell far short of the regularity which theoretically ought to result from the employment of definite quantities of materials whose chemical affinities were fully ascertained. It had appeared reasonable to expect therefore that the employment of a balling furnace worked by self-acting mechanical means would be attended by results more consistent with theory or would exhibit greater regularity than the furnaces worked by manual labour; but in point of fact he had found the character of the work turned out by the mechanical furnace was not any better than that from the ordinary furnace; indeed he was not yet sure that the result from the revolving furnace was equal to that from the hand-worked furnace. At the Jarrow Chemical Works, where he had first seen the revolving furnaces

in operation, the whole of the products of these and of the ordinary furnaces were mixed together indiscriminately, and the only way therefore of determining in that case what the new furnaces were doing was by a calculation from the previous experience of the old furnaces. To obviate any source of error from this cause, the revolving furnace at Washington had been erected in a separate building from the ordinary furnaces, and the products kept entirely separate from those yielded by the other furnaces; and he was sorry to say that the results, as regarded either the strength or the quality of the soda produced, had not yet been found to be quite equal to those obtained with the old furnaces. In respect to the yield, or the quantity of carbonate of soda or caustic soda that was obtained from a ton of the sulphate, the deficiency in the actual produce, as compared with the theoretical yield arrived at by chemical calculations, amounted to about $7\frac{1}{2}$ per cent. in the ordinary furnaces, while in the revolving furnace the deficiency was rather more. On the other hand there was a small saving in cost of labour with the revolving furnace, which he had found to be about 1*s.* 5*d.* per ton of the soda ash; this was about equivalent to the saving stated in the paper of 1*s.* per ton of sulphate, the theoretical yield of a ton of sulphate being about 15 cwts. of soda ash. Upon the regular make of the furnace the annual saving at this rate was about £173; and after deducting the interest upon the old furnace which was superseded by the revolving one, the saving left was only £150 per year. As the outlay required for erecting the revolving furnace to effect this saving amounted to £2000, he feared such a result was not sufficiently encouraging to lead to an extended adoption at present of the revolving furnace in place of the ordinary furnaces worked by hand.

Mr. C. Cochrane mentioned that in the application of a similar plan of revolving furnace for the purpose of puddling iron by mechanical means, of which a description had been given at a previous meeting (see Proceedings Inst. M. E. 1867 page 151), the great difficulty had been to find a material that would form a sufficiently durable lining of the puddling vessel; and the mechanical effect of the wash of melted metal in the revolving vessel had proved

so seriously detrimental to the best lining materials that could be procured, as to cause the ultimate abandonment of the attempt to perform the puddling of iron in that way. In the revolving chemical furnace now described he enquired whether the action which produced the wear of the firebrick lining was of a chemical nature or mechanical; and how long the lining lasted in the revolving furnace as compared with the ordinary furnaces, and also whether any other material than firebrick had been tried for the lining, such as the ganister used in the Bessemer converting vessels.

Mr. Henry C. Allhusen replied that it had been found, from the experience of the two years' working, that the firebrick lining of the revolving cylinder might be considered to stand nearly three years; and that the lining of the firing furnace attached to the cylinder lasted about twelve months, as compared with about nine months' duration of the lining in the ordinary furnaces: and he had therefore not thought it necessary to try any other lining materials in the revolving furnaces at his own works. The projecting breakers in the cylinder became worn away much more rapidly than its lining, and the fire-clay blocks of which they were composed required to be renewed every four months, in comparison with five to six months' duration of the working bed in the ordinary hand furnaces.

Mr. W. Clay mentioned that in melting spiegel-eisen for the Bessemer process he had lined the melting furnace with a material consisting of a mixture of coke and tar well rammed in, and had found this formed a very durable lining.

Mr. I. Lowthian Bell remarked that it was not possible to make any comparison between the puddling of iron in the revolving vessel referred to and the conversion of soda in the furnace now described, because there was not any analogy between the actions to which the lining was exposed in the two cases. In the revolving puddling vessel the highly heated oxide of iron had a destructive chemical action upon the silica and alumina contained in any fire-clay lining, in addition to the mechanical injury produced by the violent movement of the heavy mass of melted or solid metal in the vessel; but the chemical action of soda upon the lining of the revolving ball

furnace was not very intense at the temperature required, the heat actually required in the soda furnace being much less than in puddling. The destructive action to which the lining was exposed was therefore of a very different nature in the two cases. A lining of coke and tar, such as was found advantageous in a furnace employed for melting iron, would not be applicable in the soda furnace: in the former case the decarbonisation of the melted iron by the presence of atmospheric oxygen was attended with very little action upon the carbon in the lining; but in the soda furnace, where the object was to deoxidise the sulphate of soda by the presence of the carbon supplied in the charging mixture in the shape of coal, a lining composed of carbon would necessarily be destroyed at once in the reduction of the sulphate, the oxygen in the sulphate combining with the carbon in the lining to form carbonic acid or carbonic oxide. Various materials had been tried for the lining of the revolving soda furnace at Washington, and among them one known as "fire-stone," which was a variety of sandstone obtained from the neighbourhood; but it had been found that no material was equal for the purpose to the very best firebrick that could be procured. The mechanical action of the material rolling over in the revolving cylinder did not produce much effect he thought upon the general surface of the lining, but only upon the projecting breakers, which were the parts that suffered the greatest amount of wear, requiring to be renewed every three or four months; and he did not think the revolving furnace would be thoroughly successful in working until a more durable material was found for the construction of the breakers. Over the rest of the surface of the lining the deterioration of the material in the working of the furnace was principally due to the heat of the fire; and the action, both chemical and mechanical, of the soda was not of a very serious character. Indeed taking into account the greater quantity of material that was worked in the same time in the revolving furnace, he had found the durability of the lining greater in the revolving furnace than in the ordinary reverberatory soda furnaces; for in the latter the lining lasted only about nine months, working $21\frac{1}{2}$ tons of sulphate of soda per week, while in the fire-

place heating the revolving cylinder the lining lasted about twelve months, working 63 tons per week.

Mr. E. A. Cowper observed that, from the fact of a smoke chamber being provided beyond the revolving cylinder for the reception of the solid particles carried forwards by the strong draught, it would appear the strength of the draught employed must be considerable; and he supposed the object of using so strong a draught was to bring down the flame close enough to the surface of the materials lying in the bottom of the revolving cylinder, the top of the cylinder in this construction being evidently at a considerably greater height above the materials than the roof of an ordinary reverberatory furnace. He enquired whether any difficulty had been found in attaining the proper temperature for effecting the conversion of the soda in the revolving furnace; and whether a hotter fire was required for the purpose in that furnace than in the ordinary reverberatory soda furnaces. He suggested that the plan of heating by gas might be advantageously applied in such a case as this, thus obviating the necessity for so strong a draught through the furnace, and causing the heat to be more concentrated upon the materials on the bottom of the furnace.

Mr. Henry C. Allhusen replied that small particles of chalk on account of their lightness were carried forward by the strong draught through the revolving furnace; and it was not the object of the smoke chamber to prevent the loss of this inconsiderable quantity of chalk, but to prevent its being deposited further on in the evaporating pan, where its presence would be detrimental to the value of the liquid ball soda. No difficulty had been experienced in maintaining the heat of fire required for working the revolving furnace, notwithstanding the higher temperature that was necessary as compared with an ordinary reverberatory furnace. No other plan of heating the revolving furnace had yet been tried in place of the ordinary coal fire used for the purpose.

Mr. F. J. Bramwell enquired how it was that the cost of repairs in the revolving furnace amounted to so much as 1*s.* 4*d.* per ton of sulphate, as compared with 10*d.* in the ordinary furnaces; because he supposed the repairs were mainly required for the lining of the

furnace, and it appeared from the experience which had been obtained respecting the durability of the lining that this was quite as great in the revolving furnace as in the ordinary ones.

Mr. CLAPHAM replied that the repairs in the revolving furnace were required in other parts besides the lining of the firing furnace and the revolving cylinder; and in particular the centre hole at the furnace end of the cylinder, and the loose collar at the same end, which were lined with firebrick, required relining every six months; and the firebrick blocks of the breakers in the cylinder had to be renewed every four months. The main object for which the revolving furnace had originally been contrived was the saving of fuel, and up to the present time it must be admitted that this object had not been satisfactorily accomplished; but as more experience was gained and more attention paid to the subject, he expected the difficulties at present met with would be overcome, and the advantages anticipated from the furnace would then be realised.

The PRESIDENT remarked that, although the manufacture of soda was mainly a chemical question, it involved several mechanical considerations; and there was so close a connection between the different physical sciences that mechanical engineering could not be pursued apart from the collateral branches of science with which it was brought into relation. He thought it therefore very desirable that papers of a mixed character, like the one which had now been read, should from time to time be brought before the meetings of the Institution.

He moved a vote of thanks to Mr. Clapham and Mr. Allhusen for the paper, which was passed.

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The following paper was then read:—

# ON TOWING BOATS ON CANALS AND RIVERS BY A FIXED WIRE ROPE AND CLIP DRUM.

By Mr. MAX EYTH, of Leeds.

In the application of steam power to River and Canal Navigation the greatest obstacle to be encountered has been the loss of power that is inseparable from the ordinary methods of propulsion by paddle wheels or screw propeller. As the receding water here forms the fulcrum upon which the bearing is taken for propelling the vessel, the result is that a great quantity of water is put in motion and a considerable amount of power exerted without any useful effect being produced. Thus even under the most favourable circumstances, when working on a broad sheet of deep water, the ordinary propellers lose from 40 to 50 per cent. of the power applied to them; and under the peculiar circumstances met with on rivers and canals their useful effect is frequently reduced to less than 25 per cent. of the power applied.

On canals, the increased difficulties to be encountered arise from the presence of locks, the small section of water through which the boats have to be driven, and the swell produced by the increased speed of the boats, the small section of water not having been originally calculated for such a speed. Moreover as the only admissible means of propulsion is by screws or paddle wheels placed at the stern, the water put in motion by them is withdrawn from the stern of the tug, and thrown against the bows of the boats in tow; the water level in the canal is thereby disturbed, and the hollow created at the stern of the tug has to be filled up by the water in front of the tug running backwards through the narrow passage left between the tug and the sides of the canal. This motion of the water being in the opposite direction to the advance of the tug, the skin-friction is greatly augmented, especially at the bottom of the vessel.

The consequence is that engines of considerable power have to be used for towing a given freight; and as the size and capacity of the boats in use on any canal are limited by the size of the locks through which they have to pass, it becomes of the utmost importance that the engines employed should occupy as little space as possible in the hold of the vessels, in order that the cost of steam propulsion may not be further increased by a serious diminution in the amount of freight that can be carried. Owing to the frequency of locks, which are generally constructed for the passage of only one boat at a time, the employment of larger tugs working a train of several barges is in most cases inadmissible, as each lock would stop the entire train during the whole time required for passing each barge separately through the lock.

On rivers, in addition to shallow places and small sections of the navigable channel, the principal impediments to steam navigation are the varying currents, by which the effect of the paddle-wheels or screw is reduced sometimes to a mere nominal amount. On the Rhine, for instance, it is a common occurrence for the large steam tugs of 500 effective horse power, drawing three boats, to continue working full power against the currents near Bingen and St. Goar without making any advance. Ten or twelve horses are then attached to the tug, and are able without much difficulty to draw the whole train through the rapids of the river.

Under all circumstances of navigation, and especially under those usually met with on rivers and canals, a dead pull from a fixed point must undoubtedly be a more effective mode of applying power than any method depending upon the resistance of the water as the fulcrum against which the propelling power is exerted; and this principle of a direct pull has accordingly been adopted as the basis of the system of navigation which forms the subject of the present paper, for towing boats on canals and rivers by means of a fixed wire rope and clip drum. The wire rope is laid in the bed of the canal or river from end to end, being anchored only at its two extremities; and an engine fixed upon the tug takes hold of the rope by means of a clip drum, round which the rope is passed. The clip drum being put in motion by the engine winds itself along the rope,

lifting it up from the bottom of the canal in front of the tug, and dropping it again into the water behind. The engine thus exerts a direct pull upon the rope, which in consequence of its weight and the friction upon the bed of the canal does not materially alter its position. By this means the whole of the power applied to the clip drum is utilised in the propulsion of the boat, independent of the currents of the water or the section of the channel.

The idea of towing by means of a submerged rope or chain is by no means new, attempts in this direction having been made on the Rhine as early as the year 1732 by the French Maréchal de Saxe, for transporting war material through difficult parts of the river, by means of a horse windlass on the boat, winding up a rope made fast at the other end upon the river bank; on arriving at the end of the rope the boat was moored, while the rope was drawn out and secured again at a point higher up the river. In 1820 a regular service on this principle was established on the Rhone by Tourasse, and successfully overcame the very difficult parts of the river between Givers and Lyons; the tug boat carried an ordinary capstan driven by a steam engine, and was accompanied by two small auxiliary steamers acting as tenders to the tug, each containing a winding drum carrying a length of 1100 yards of hemp rope 2 inches diameter. One of these tenders ran ahead, paying its rope out into the river and fixing it at the upper end to a mooring post; the tug boat meantime wound itself along the other rope previously laid, and the rope was delivered from the capstan of the tug boat to the winding drum in the second tender lying alongside, which afterwards ran ahead with it as soon as the end was reached. In this manner the tug worked its way along, using the two ropes alternately, without great loss of time.

The employment of a chain in place of a rope was twice attempted on the Saone between Lyons and St. Bernard; and in 1850 a steam tug working on a chain was started on the Seine, since which time two lines of chain navigation have been in active operation on that river, and still continue so, one extending 32 miles from Paris down to the mouth of the Oise, and the other rather a greater distance up

to Montereau. The chains employed are of very great strength, being made of iron $\frac{3}{4}$ to 1 inch diameter, in order to stand the violent shocks to which they are exposed by the passage of the tug boats. The tugs are 130 feet long by 23 feet beam, with 7 feet depth of hold and 16 inches draft; and they carry engines of 60 horse power working a pair of winding drums on parallel horizontal axes. The chain passing over leading pulleys at the bow and stern is led over the deck in a trough and supported by a number of carrying pulleys, and makes four or five turns round the pair of drums. The tug has a rudder at each end for running backwards or forwards, as it is not able to turn under the chain. The principal drawback in the working of these boats arises from the great weight of the chain, which has consequently a considerable inclination to the horizon in passing over the front leading pulley; the pull of the engine being thus exerted in an inclined direction, instead of nearly horizontally, the bow of the tug is depressed in the water; and the additional expenditure of power thereby occasioned becomes in deep water so considerable as to render the employment of a chain less advantageous than that of an ordinary propeller, the effect of the latter increasing with the depth of immersion.

Another difficulty in the use of a chain is the steering of the tug, as the great weight of the chain and its clinging to the river bed impede the lateral movement that is required of the tug, wherever the chain happens to lie out of the middle of the river. Where the traffic goes principally in one direction, the chain gradually gets pulled tight against the inner bank of the curves in the river; and in this case it is necessary to cut the chain, insert additional links, and draw it back into the middle of the river by manual labour, an operation which has frequently to be resorted to on the Seine. The jerks upon the links in the working of the chain tend to produce breakages, which generally happen in those parts of the river where the currents are strongest; and the chain is also liable to break in passing over the winding drums, in consequence of one coil jumping on the top of another on the drums and thereby being driven at a greater velocity than the rest of the chain round the drums. This occurs especially in going downstream at a considerable speed,

at which time the chain is running rather slack on the drums. On the Elbe, where the same plan is also in use, fractures have been rare, in consequence of the unusual strength of the chains employed; but the increased weight and cost of such chains are serious objections to their adoption. As it is impossible for two tugs working with winding drums to cross each other on the same chain, and as two chains are also impracticable owing to the liability of one overlying the other in the river bed, an attempt was made by Bouquié to employ pitched pulleys taking hold of the single links of the chain; but the unequal stretching of the links and the wear and tear of the pulleys caused the chain to slip and jump off the teeth of the pulleys.

The system of Wire-Rope Navigation, consisting in the employment of a clip-drum working along a submerged wire rope, has been invented and matured by Baron Oscar de Mesnil and the writer of the present paper, the first experiments for the purpose having been made at Leeds in 1866 by Messrs. John Fowler and Co., under the direction of Baron de Mesnil, a Belgian gentleman, who has for many years devoted his attention to inland navigation. These experiments were afterwards repeated on a more extensive scale upon several American canals and also in Belgium, the results obtained being in every respect favourable; and the system has consequently been established upon a number of canals and rivers. The first application of this system was on the river Meuse, where a line of wire rope of 42 miles length from Namur to Liège has been in successful operation from June 1868, and is now about to be extended 90 miles through the Canal de la Campine to Antwerp. This will give a continuous line of 132 miles, partly canal and partly river, presenting examples of almost all the ordinary difficulties met with in inland navigation. Wire ropes have also been laid on the Canal de Charleroi in Belgium, where a long and narrow tunnel offers great difficulties to the ordinary towing by horses; and also on the maritime Canal de Beveland in Holland, between Rotterdam and Antwerp; and on the Canal de Terneuze, which connects Ghent with the Scheld and is

accessible for large sea-going vessels. Other lines are about to be established on the Danube and the Rhine; and for the latter a vessel is now building for the purpose of a series of experiments in the more difficult parts of the river.

In Figs. 1 and 2, Plate 57, is shown the 10 horse power tug employed on the Canal de Charleroi in Belgium. The boat is 62 feet long, 8 feet broad, and 6 feet deep in the hold, drawing about 3 feet of water; the hull is entirely of iron, the bow and stern being alike for running in either direction. There is a large rudder at each end, 8 feet long by 3 feet high; and the keel is made unusually deep, projecting 1 foot below the flat bottom of the boat, as shown in the transverse section, Fig. 6. The large rudders and deep keel are found of great service in the sharp curves of the canal, where the tug is able to tow a train of from fifteen to eighteen barges of 70 tons burden each. The boiler is placed longitudinally in the after part of the hull, and is of the ordinary locomotive construction, having 200 square feet of heating surface and $6\frac{1}{4}$ square feet of grate surface. When working in the canal tunnel, the exhaust steam is condensed by being blown into the water of the canal, and the draught for the fire is produced by a small fan driven by the engine; outside the tunnel the draught is produced in the ordinary way by the discharge of the exhaust steam.

The engine is shown to a larger scale in Figs. 3 and 6, Plates 58 and 59; it has a single 10 inch cylinder of 12 inches stroke, fixed horizontally on a cast-iron bedplate in the bottom of the boat. The crank shaft A has a small flywheel B on one end, and on the other a friction clutch C, the loose half of which is cast in one piece with two bevil wheels D D of nearly equal diameter, gearing with two bevil wheels E F of different sizes on a vertical shaft G; a small pinion I on the top of this shaft gears inside the rim of the horizontal clip-drum H on the deck of the tug. The two bevil wheels E F on the vertical shaft G slide on feathers on the shaft, and are connected together by a long cast-iron neck; and by means of a large nut J working on a screwed portion of the shaft, either of the two wheels is thrown into gear with the crank shaft, thus giving two different speeds for the clip drum.

The wire rope employed, R R, Fig. 4, is $\frac{5}{8}$ inch diameter, and the clip drum H working upon it is 5 feet diameter, and turns loose on a centre stud fixed on a wood crossbeam flush with the deck, as shown in Fig. 3. A second stud carries the double-grooved guide-pulley K, which is set slightly inclined, so that the rope passing off horizontally from the two sides of the clip drum enters the upper groove on one side of the guide pulley and the lower groove on the other side. Between the clip drum and guide pulley and also in the grooves of the guide pulley the rope is guarded by a light cast-iron trough or casing lined with wood, as shown to a larger scale in the section, Fig. 5; the portions between the drum and pulley are cast in two halves to allow of readily opening whenever the rope requires to be taken out.

Two pressing pulleys L L, Fig. 4, held up by springs, press the rope into the clip drum, one of them only being generally in use at a time, for pressing the tail rope into the clips at the point where it quits the drum, according to the direction in which the tug is going. The rope is guided on and off the double-grooved pulley K by two small vertical pulleys M M overhanging the side of the tug; and from the hinder of these pulleys the tail rope is usually allowed to fall direct into the water, as shown in Fig. 1. A leading pulley N, Fig. 1, swinging on a universal joint, as shown in Figs. 7 and 8, Plate 59, is suspended near each end of the tug, the pulley for the front rope only being in use at any one time.

A small winding drum P, Fig. 17, is provided on some of these tugs, turning loose on the centre stud of the clip drum, with which it can be connected by a pin, for the purpose of winding an auxiliary rope for towing barges through the locks on the canal, while the tug is lying stationary alongside. The principal use of the winding drum however is to obtain a sufficient amount of slack in the wire rope for enabling the tug when off the rope to hitch on again at any place, without having to go to the extreme end of the rope. For this purpose the wire-rope is picked up generally in the neighbourhood of a bend on the canal, where there is always some slack to be found, and is fixed securely to the bow of the tug; the auxiliary rope from the winding drum being then fastened to the wire-rope near the

stern of the tug, the wire-rope is by this means hauled in until a sufficient amount of slack is obtained for passing it round the clip drum and the double-grooved guide-pulley.

The handles S and T for starting and reversing the engine, and also the handwheel and screw Q for working the friction clutch C, are all on deck in convenient proximity to one another, Figs. 4 and 6. The friction clutch is essential with the single-cylinder engine employed on the tug, for bringing the load gradually upon it, as it would otherwise be impossible to overcome the inertia of a long train of barges, without the engine continually sticking fast on the centres. The usual speed of the engine is 80 revolutions per minute, with 90 lbs. pressure of steam; but the speed can at any time be increased without inconvenience to 100 or 120 revolutions per minute. The gearing is so arranged that at the ordinary speed of 80 revolutions the tug makes either 1 or 3 miles an hour. The very slow speed of 1 mile an hour is specially required in the tunnel, where the canal is so shallow and narrow that any greater speed would drive the water in front of the first boat of the train, so much as to cause the hind ones to get aground.

This tug was put to work on the canal a few months ago, another of similar construction having been started experimentally about a year ago; the engines and machinery of both, as well as the rest of the machinery described in the present paper, were constructed at Leeds by Messrs. John Fowler and Co.

In Figs. 11 and 12, Plate 60, is shown a 14 horse power tug on the River Meuse. The boat is 80 feet long and 13 feet beam, with $7\frac{1}{2}$ feet depth of hold, drawing 3 feet of water. As there are currents in the river, facilitating the steering, and a higher speed is admissible in this case, the keel and rudders are of smaller dimensions than in the canal tug previously described. The boiler has 200 square feet of heating surface and $7\frac{1}{2}$ square feet of grate surface, and is of ordinary locomotive construction, fixed longitudinally in the boat. The engine is a horizontal double-cylinder one, fixed on a bedplate and wooden framework in the bottom of the boat, as shown to a larger scale in Fig. 13, Plate 61; the cylinders are $7\frac{3}{4}$ inches diameter

by 12 inches stroke. As three different speeds are required with the tug, an intermediate shaft B is introduced between the crank shaft A and the clip drum H, as shown in Fig. 14; and the spur wheels are thrown in and out of gear by ordinary clutches, a friction clutch not being required with double-cylinder engines.

The clip drum is 6 feet diameter, and is placed vertically, projecting over the side of the boat by the amount of its breadth, Fig. 14. The rope R is led on and off the drum by two 6 foot guide-pulleys C C, Fig. 13, the bearings of which slide in long inclined slots D bolted on the side of the boat, and are raised or lowered by hand screws E; in their lowest position, in which they are fixed when towing, as shown in Fig. 13, each pulley is further secured by a locking nut F, Fig. 14, on the inside of the slot. The object of this arrangement is to afford greater facility for getting the wire-rope off the pulleys and throwing it overboard, when disconnecting the tug from the rope, for which purpose the locking nuts are slackened and the guide pulleys are drawn up the inclined slots by the hand screws into their highest position, as shown dotted on the left-hand side in Fig. 13, whereby the rope is completely slackened, and can be thrown off the clip drum and guide pulleys by hand with the greatest facility. The replacing of the rope is done in a similar manner, by putting it round the clip drum while the guide pulleys are in their highest position; and the latter are then screwed down upon the rope into their working position.

The pressing pulleys L for pressing the tail rope into the groove of the clip drum are worked by a flat spring, and are so arranged that while one of them is acting the other is off, one only being required at a time. The rope guards G are fixed cast-iron flanges bolted to the side of the boat and lined with wood. In screwing the guide pulleys upwards, the guards are left behind, and the rope can readily fall out of the grooves of the pulleys. The leading pulleys N, Fig. 11, at the two ends of the boat are similar to those previously described, and the universal joint by which each is suspended has a counterbalance weight attached to it, as shown in Figs. 9 and 10, Plate 59, enabling the pulley to adjust itself with perfect facility to the slanting position required by the rope.

The engine makes 70 revolutions per minute, and the three corresponding speeds of the vessel are $1\frac{1}{2}$, 3, and 6 miles an hour; the lowest speed is specially intended for working against the strong currents during the winter, while the quick speed is intended for the down traffic, and can be increased to 10 miles an hour by running the engine at 120 to 130 revolutions per minute. In three tugs subsequently built for this line, auxiliary screw propellers have been provided, for the purpose of going down stream with the propeller, so as to use the wire rope only for the traffic going up the river. One of these engines works a horizontal clip drum, which gives a very neat arrangement, leaving the deck and sides of the boat free and unencumbered; and the pressing pulleys being worked by weights instead of springs allow of using a rope in which the joints are made with shackles instead of by splicing.

In Figs. 15 and 16, Plate 62, is shown a Canal Tug worked by a Portable Engine of the smallest class used for the purpose; the engine is placed on an ordinary canal boat, and on arriving at the end of its journey can be taken off and placed on another returning boat. Usually the size of canal barges is so great that in passing locks and bridges nothing whatever can be allowed to project beyond the side of the vessel. Frequently also the bridges are so low that when the barge is empty very little space above deck is left for any parts of the machinery projecting in that direction. Also in regard to length, the locks do not allow any additional room; and to avoid diminishing the freight, as little space as possible should be taken from the hold of the barge. These conditions render the construction of suitable machinery for the ordinary canal service by no means an easy matter.

The portable engine now described, which is shown to a larger scale in Figs. 17 to 20, Plate 63, has a small tubular boiler, fired from the side of the firebox and provided with a steam dome through which the chimney passes. A single-cylinder engine of the ordinary portable-engine type is fixed underneath the barrel of the boiler; and the crank shaft A drives by a friction clutch C and pair of bevil wheels a vertical shaft G gearing with a horizontal clip drum H of

4 feet diameter, which is carried on a centre stud bolted on the top of the boiler.

The double-grooved guide-pulley K is centred upon a moveable platform B, which turns round the centre stud of the clip drum and works on a slotted circular arc D fixed upon the top of the boiler, as shown in the plan, Fig. 18. This radial platform also carries the two rope guards, consisting of cast-iron troughs lined with wood; and also the two pressing pulleys L L, which are worked simultaneously by a handwheel E acting on a screwed rod and spiral spring. The two small vertical leading pulleys M guiding the rope R into the grooves of the double-grooved pulley K are carried upon two radial arms turning on the centre stud of the double-grooved pulley. The entire engine is suspended between two beams F placed across the deck of the tug near the bow, so that the boiler stands across the boat, and the double-grooved guide-pulley K in its working position projects 1 foot or more over the side of the vessel. Whenever the tug approaches a lock, a pin which fixes the radial platform B in its ordinary position is withdrawn, and the strain of the rope itself then pulls the platform round, as shown dotted in Fig. 18, drawing in the projecting portions of the apparatus within the edge of the deck, so that the tug can pass through the lock without any obstruction. After passing through, the engine is reversed for a few strokes, causing the radial platform B to be drawn out again by the rope into its original projecting position, in which it is then secured by the fixing pin.

The weight of the whole apparatus, which is capable of towing at $2\frac{1}{2}$ miles an hour two barges of 200 tons burden each, does not exceed $2\frac{1}{2}$ tons; and its length and breadth are respectively 10 feet and $4\frac{3}{4}$ feet, the extreme height above deck being only $2\frac{1}{2}$ feet and the depth below deck $3\frac{1}{2}$ feet.

The Wire Ropes employed on the several lines now in operation vary in diameter and material according to the circumstances for which they are intended. The smallest ropes in use are those on the Canal de la Campine and the Canal de Charleroi, which are $\frac{5}{8}$ inch diameter and made of charcoal iron wire; and the largest are those for the experiments now in progress on the Rhine, which are $1\frac{5}{8}$ inch

diameter. On other lines ropes are used of $\frac{3}{4}$, $\frac{7}{8}$, and 1 inch diameter, some of them galvanised. The majority are simply charcoal iron wire ropes, but some are constructed partly of steel wire, and the rope used in the tunnel on the Canal de Charleroi is entirely of steel.

On ordinary canals, for barges of from 100 to 250 tons burden, and with the average number of locks which do not allow of trains being worked containing more than 2 or 3 barges, wire ropes $\frac{5}{8}$ inch diameter of charcoal iron are found to be quite sufficient, generally without galvanising. The breaking strain of such a rope is about $6\frac{1}{4}$ tons, and its weight 2 lbs. per yard or 32 cwts. per mile; and the cost is from £48 to £53 per mile. When the traffic is an unusually heavy one, the employment of steel wire ropes is preferable. The breaking strain of a rope of the same diameter is thus doubled, and the cost nearly so; but the additional outlay is fully compensated by the increased amount of work that the steel rope will stand. The galvanising of the wires is in this case found to be entirely unnecessary, the experience of two years working having sufficiently demonstrated that the ropes are but little affected by oxidation, as they are constantly immersed several feet under water, and never exposed to the air long enough to become dry. On larger canals and especially on maritime canals, in cases where the speed is not considerable, but where large ships or long trains of vessels have to be towed, the wire ropes should be $\frac{3}{4}$ to $\frac{7}{8}$ inch diameter. An iron wire rope $\frac{3}{4}$ inch diameter weighs $2\frac{1}{2}$ lbs. per yard or 2 tons per mile, and the cost per ton is slightly less than that of a $\frac{5}{8}$ inch rope, so that the cost per mile amounts to £60. The breaking strain of the $\frac{3}{4}$ inch rope is $8\frac{3}{4}$ tons, and of the $\frac{7}{8}$ inch rope $12\frac{1}{2}$ tons. Steel ropes of smaller diameter in proportion to their increased breaking strain may be used with great advantage. For ropes laid in salt or brackish water it is indispensable that the wires should be protected from oxidation either by galvanising or by a covering of tar and beeswax. The latter protection has the advantage of being easily renewed at any time without having to take the rope out of the canal; and it also obviates the injurious action that occurs of the zinc upon the iron when oxidation has once started in a galvanised wire rope.

On rivers, in consequence of the currents varying with the locality and the season, stronger ropes are required, of not less than 1 inch diameter, having a breaking strain of 15 tons and weighing from $4\frac{1}{2}$ to 5 lbs. per yard or $3\frac{3}{4}$ tons per mile, their cost being about £95 per mile. Where the required diameter of an iron wire rope would exceed $1\frac{1}{4}$ or $1\frac{3}{8}$ inch, it is advantageous to substitute a steel rope of equal strength, the cost of which will not much exceed, if at all, that of the iron wire rope. On lines of iron wire rope it will also be of great advantage to lay lengths of steel wire rope of the same diameter in the more difficult parts of the river, as in locks or in strong currents or very sharp bends, or where the bed of the river is particularly rocky, in order thereby to preserve a uniform degree of security throughout the whole length of the line of rope.

The laying of the wire ropes is a simple and inexpensive operation. They are generally supplied in lengths of a single mile each, coiled in the ordinary manner; the coil is placed on a vertical wooden windlass on the boat, and the rope is payed out over the stern, the boat being towed either upstream by horses, or better downstream by a small steam tug. A simple break is provided for tightening the rope as required during the paying out, the general practice being to lay it pretty tight along the straight portions of the line, and pay it out more slack in the bends. When the length of one mile has been payed out in this way, its end is spliced to the next coil; and 5 or 6 miles can be laid in a day without the slightest difficulty.

In the application of the power in the system of wire-rope navigation, the requisite hold upon the rope for the purpose of towing is obtained by means of the Clip Drum. As this ingenious contrivance, the invention of which is due to Mr. R. Burton of Leeds, offers the only practical means at present known of taking hold of an endless rope with absolute security, its application has now become very general for steam ploughing, mining operations, and other purposes where large amounts of power have to be transmitted through considerable distances. Its application now described for the purpose of towing in navigation is the first instance in which the rope remains stationary while the clip drum travels along it.

As the effect produced by the series of clips gripping the rope round the circumference of the drum is simply equivalent to increasing the friction of the same rope round the circumference of a plain drum, a similar expression in each case gives the ratio between the strains on the leading rope and the tail rope, which increases with the extent of the arc of circumference or the number of clips that the rope passes over on the drum. In order therefore to obtain any given amount of pull upon the leading rope, it is necessary that a proportionate degree of tension upon the tail rope should be constantly maintained; and as the tail rope in towing passes off slack from the drum, occasionally without any tension upon it, the required effect of tension upon the tail rope has in this case to be obtained by some other means; and this object is accordingly accomplished by the adoption of a pressing pulley, which acts in a direction radial to the drum, and is applied at the point where the tail rope leaves the drum, pressing the rope by a spring or weight into the grip of the last pair of clips on the drum, as shown at L L in Figs. 4, 13, and 18. The clip drum is thus the only contrivance at present in use by which a smooth rope can be firmly laid hold of, while leaving the tail rope completely slack, and at the same time without occasioning any injury to the shape or material of the rope by any excessive compression in grasping it; and the clip drum is therefore the principal mechanical feature in wire-rope towing, without which the system would be impracticable.

The position of the clip drum, and of the guide pulleys guiding the rope on and off it, is either horizontal or vertical. In the horizontal arrangement with double-grooved guide-pulley, as shown in Plates 58 and 63, the leading rope generally lies in the upper groove of the guide pulley, and the tail rope in the lower groove. In the vertical arrangement, shown in Plate 61, the extent of circumference round which the rope passes on the clip drum is sometimes increased in the case of small engines to three quarters of a revolution or nearly a whole turn round the drum, by employing only a single guide pulley placed just below the drum; the leading rope then enters on the bottom of the drum nearly horizontally, and the tail rope passes off it over the guide pulley at nearly the same place.

In the passage of the rope round the guide pulleys, and especially in running between these and the clip drum, it has to be carefully guarded from jumping out of the grooves or getting entangled if at all slack. It has been found by experience that most careful attention has to be paid to this point; and the rope guards employed for the purpose consist of cast-iron troughs lined with wood, as shown in Figs. 4 and 13. The rope is in all cases led along the side of the tug, instead of over the deck in the centre line of the vessel, this arrangement being adopted on account of the great facility which it affords for getting rid of the slack rope behind the machinery. Where a very great towing power is required, it would no doubt be advisable for the rope to be central; and the greater stiffness of the larger rope then employed would of itself do away with the inconvenience which would occur on smaller tugs from the occasional slack of the tail rope. The leading pulley over which the rope passes at either end of the tug is about half the diameter of the guide pulleys guiding the rope on the clip drum, as shown in Figs. 7 and 8, Plate 59; and the universal joint by which it is suspended is made simply by two wrought-iron rings, allowing the pulley to swing according to the direction which the rope assumes, and thus effectually preventing the rope from jumping out of the groove. Generally the front rope alone passes over the leading pulley, while the tail rope is allowed to fall direct into the water on leaving the guide pulley of the clip drum, although in so doing it occasionally rubs against the side of the tug.

The most important advantage attending the system of wire-rope navigation consists in the fact that nearly the whole of the power applied for the propulsion of the boat is here utilised. The main source of loss of power in this system is the slanting direction of the pull,* in consequence of the rope lying at the bottom of the river or

* The writer has since satisfied himself that the inclination of the rope entails no loss of power, and that the whole of the engine power is utilised in the horizontal forward motion of the boat, the only effect of the inclination of the rope being to increase very slightly the depth of immersion of the boat in the water and the consequent resistance of the water to its motion.

canal; but the trifling amount of the loss resulting from this cause may be illustrated by the case of the tug already described, working on the river Meuse. In this instance the average depth of water is 12 feet, the weight of the rope 1·3 lbs. per foot, and the pull exerted at the clip drum $1\frac{1}{2}$ to 2 tons or say 4000 lbs. The length of rope lifted off the ground ahead of the tug is therefore 270 feet; and its inclination at the leading pulley is such that the useful draft is reduced to 3984 lbs., being a reduction of only 16 lbs. on the original draft of 4000 lbs., or a loss of power of only 0·4 per cent. The mere lifting of the rope from the bed of the river does not occasion a loss of power, because the rope falls again to the same level behind the tug, so that one movement counterbalances the other, excepting only to the extent of the adhesion of the rope in the river bed. The vertical pressure upon the leading pulley by the weight of the unsupported length of 270 feet of rope amounts to 352 lbs., which increases the immersion of the tug to the extent of only 1-6th inch, so that the effect upon the motion of the tug is altogether inappreciable. The friction of the clip drum and pulleys, and the bending of the rope round them, can occasion only a very trifling loss of power, as there are only three bends altogether, and the pulleys and drum are all made of large diameter and move at a slow speed. Also the tendency of the tug to assume a slanting position in plan, in consequence of the draft being at one side instead of in the centre line of the boat, has only a nominal effect; for if the tug has a number of barges in tow, their attachment to it is of course made out of the centre line, on the same side on which the rope acts, so that their resistance brings the tug back to the straight line; or if no barges are in tow, a slight inclination of the rudder keeps the tug perfectly straight. The only remaining loss of power is that which occurs in passing round the bends in the river or canal, where a displacement of the rope is occasioned by the passage of the tug; but when all these sources of loss of power are added together, there is no probability of the total loss amounting under any ordinary circumstances to more than 3 or 4 per cent. of the power applied to the clip drum, or say 6 or 7 per cent. of the power given out by the engine.

In working against a strong current or at a high speed, the useful effect obtained with the wire-rope system is slightly increased, owing to the rope in front of the tug being stretched into a more nearly horizontal position, so that the pull becomes still more direct; and thus, whilst the effect of paddle wheels or screw propellers is diminished in working against a current, the wire-rope tug works better, the greater the difficulties it has to overcome. The perfectly smooth and noiseless working of the rope round the clip drum and guide pulleys admits of almost any speed being attained that is compatible with the nature of the river or canal and the power available; and in this respect the wire rope has an advantage over a chain, which cannot be worked beyond a certain limit of speed, on account of the serious vibration and shocks produced in its passage over drums and pulleys.

The passage of the tug through the locks is accomplished without any interruption in the continuous line of the rope. The mode of effecting this is shown in Figs. 21 to 23, Plate 64, which represent one of the locks on the river Meuse. At the bottom of the gates a small aperture is made for the passage of the rope through the joint of the gates when closed, by cutting a small piece out of each gate; and when the gates are open, the rope is perfectly free to be lifted and sunk again by the tug, which works its way in and out of the lock exactly as in the open river. The gates in closing sweep the rope back again towards the centre line of the lock, so that no attention whatever is required for replacing it in the centre.

Where the construction of the lock gates is such as to entail any risk of the rope getting jammed underneath the bottom of the gate in closing, a couple of curved angle-irons bent to the circle described by the gates are fixed on the bottom of the lock, standing up a few inches above the sill, as shown at A A in Figs. 24 and 25; and each gate is provided at its bottom corner with a vertical iron bolt or finger B, which in closing sweeps along the flange of the angle-iron, reaching an inch or two below its upper edge. By this means the rope, which always lies somewhere over the angle-iron, is swept towards the middle of the lock into the exact position of the opening through which it passes in the closed gates.

One of the most important practical questions with regard to the working of the wire-rope system was whether the tugs would steer readily under all circumstances, but especially in sharp bends, where it was expected that a gradual if not a sudden shifting of the rope towards the inner side of the curve would inevitably be occasioned. On long straight lines the question was quickly settled most satisfactorily, as the great distance ahead at which the rope is lifted from the ground, and the slackness of the tail rope, allow the tug perfect liberty to move at an angle of more than 45° to the rope, within reasonable limits as to the extent of the lateral movement. The steering in curves is illustrated in the diagrams, Figs. 26 to 29, Plate 65. On approaching a bend, as in Fig. 26, it is observed that at a considerable distance before entering the bend the engine suddenly makes several quick revolutions, as though running empty, in consequence of the rope at that moment being drawn out of the centre of the river towards the inner side of the curve. The slack thus gained being payed out behind the tug, as in Fig. 27, is temporarily deposited in the river bed at a place probably several hundred feet before the commencement of the bend. On entering the bend the tug is steered so as to keep off the inner bank; and the steering force acting at right angles to the rope, as in Fig. 28, produces a tension on the tail rope as well as the front rope, much greater in amount than that by which the rope was originally shifted. The slack previously deposited behind the tug is thus drawn forwards again into the bend of the river, the tug following the centre line of the river and laying the rope back again into its original central position, as in Fig. 29. So completely is this effected that after a year's service on the river Meuse the rope is found in all the principal bends of the river to lie on the very outside of the navigable channel; and this result suggests a mode of restoring an even degree of tightness to the rope in places where on long straight lines it may have become stretched too tight, the original amount of slack being restored to the rope at those places by the simple expedient of steering the tug out of its straight course, making it travel in a zig-zag line between the two banks.

With regard to the crossing of tugs working in contrary directions on a single rope, although the throwing overboard of the rope for this purpose by either of the tugs is greatly facilitated by the vertical arrangement of the clip drum, as shown in Plates 60 and 61, yet on lines where there is much traffic the inconvenience and loss of time which cannot be entirely avoided in this operation render it advisable either to adopt some system of management whereby tugs shall not usually have to cross each other, or else to lay two ropes, one for the up traffic and the other for the down; and even a small amount of traffic is sufficient to repay the extra outlay for a second rope. Should the two ropes happen anywhere to overlie each other, and should the next tug passing be working along the under one, the smooth surface of the ropes offering no projections allows the top rope to slip freely off the under one, thus obviating the only objection that could be urged against the employment of a double line of rope. As an additional precaution a protecting fork is fixed on the tug in front of the leading pulley, to guard against risk of accident in any extreme case. If only a single rope be employed, the crossing of tugs may be avoided either by letting the two tugs exchange their trains of barges at the place where they meet, each tug then returning the way it came; or else by working each tug between two particular stations only; the latter plan however requires a very regular traffic, and cannot therefore be generally recommended.

With regard to the wear and tear of the wire ropes and their probable duration, the experience of two years' working has shown that they are not exposed to injury by oxidation, the water itself forming a secure protection to them in this respect. It is only in very shallow places, where also there is a very rapid current causing a little air to get mixed with the water and carried down to the bottom, that any spots of rust are found upon the ropes; but they are so slight in extent that even in these places the ropes may be expected to last thirty years without suffering any serious deterioration.

The effect of the mechanical action produced upon the wire ropes by bending and friction on the pulleys may be judged of from the

facts obtained in other applications, were there is the experience of longer periods of working. In steam ploughing, for instance, a steel wire rope is bent some 40,000 times over a clip drum before requiring renewal; and in this case it is at the same time constantly running over small carrying pulleys and also rubbing along the ground. Similarly ropes in mines and on inclined planes are exposed not only to bending and friction over the machinery itself, but also to rubbing against surrounding objects in consequence of the ropes themselves being in motion. In towing however, the rope itself lies entirely at rest, and is only in use at the moment of the tug passing, at which time it is lifted from the bottom by the leading pulley of the tug and bent round three pulleys of large diameter. From these considerations, combined with the present condition of the ropes already in use for towing, there is reason for anticipating that good wire ropes made of charcoal iron not galvanised, working under the circumstances of any ordinary river or canal navigation, may be relied upon to last for at least ten years; so that the first cost of the rope and its subsequent deterioration become comparatively unimportant. In maritime canals, it is indispensable that the wire-ropes should be protected by galvanising, or by some other less injurious mode of preserving them. In a rapid river having a bed of small loose stones, as in the case of the Rhine, only ropes of hard steel and composed of wires of considerable diameter should be employed.

Any risk of the rope becoming silted up in the river bed could only be occasioned by heavy floods after a long severe winter; and where a river is locked up for several months during the winter, the rope should be drawn on shore for the time, and put in place again when the navigation is reopened. Accidental obstructions occasionally met with in the river beds arise from lost anchors, sunk trees, or large loose pieces of stone, getting caught and brought up by the rope. This frequently happens on first starting a new line; but after a month or two the channel becomes cleared by the rope itself, and accidents from this cause are exceedingly rare, and have never resulted in any serious breakage, although on the river Meuse the rope has brought up a dozen anchors and on one occasion an entire cart.

No fractures of any of the ropes have occurred up to the present time; and the pull upon the rope so long as it is not exposed to sudden jerks may with perfect safety be carried up to one third or even half of its breaking strain. Any bad places in the rope affect single wires only, so that in the same section there are still a number of good wires strong enough to stand the ordinary pull. In the event of a break the splicing of the rope would be the work of an hour only, and the splice if properly made is actually stronger than the other parts of the rope, the central hemp core being replaced at the splice by a strand of iron wire. When the pressing pulleys of the clip drum on the tug are held up by weights instead of by springs, the rope may be provided with ordinary steel shackles, and laid in lengths of only a quarter or half a mile each, which will in many cases prove to be an advantage fully compensating for the slight additional outlay required for the purpose.

On the line of wire rope in the river Meuse, extending over the 42 miles distance between Namur and Liège, there are eleven locks regulating the depth of water and the currents in the river; and the depth now admits any boats drawing less than 7 feet of water, up to 300 to 400 tons burden. The velocity of current averages only 2 to 3 miles an hour in summer, but in winter and spring it amounts sometimes to from 8 to 10 miles in the more difficult parts of the line. The river bed is very uneven, the depth of water varying from 8 to 25 feet, and the bottom consists of mud, gravel, sand, and rocks, in different places; and in the upper part of the river there are some very sharp bends in its course. The rope in use is 1 inch diameter, made of iron wire and the greater part galvanised; its breaking strain is 14 tons, the weight $4\frac{3}{4}$ lbs. per yard, and the cost, including laying down in the river, £93 per mile. There are four tugs in operation, of 14 to 20 nominal horse power, which generally work at about 4 miles an hour against the current of 2 or 3 miles an hour.

The maximum work done by the 14 horse power tug first placed on the river consisted in towing 18 boats partly freighted, containing a total cargo of 1000 tons; and in another instance the same tug

towed 1500 tons of freight in 10 boats. Both trips were made going up stream at the usual rate of $2\frac{1}{2}$ to 3 miles an hour including stoppages. The average work of the tug is the towing of 700 to 900 tons in 8 to 12 boats of different sizes. Owing to the unavoidable delays at the locks the mileage per day is at present small, averaging only 20 to 22 miles in 10 hours; but in consequence of the successful working of the line it has lately been decided to increase the length of the locks, so that the whole train of barges may be worked through with only one opening of the lock-gates. As soon as this is done, the mileage will easily be raised to 30 or 40 miles per day.

The average consumption of coal by the 14 horse power tug amounts to $\frac{1}{2}$ ton per day, or about $\frac{3}{4}$ cwt. per mile, when working a full train of 8 to 10 boats; and the working expenses have averaged during the year about £22 per month. No accidents whatever have occurred, and the service has been maintained throughout the past winter, even during the time when in consequence of the high water the ordinary navigation was entirely stopped, and the passenger steamers between Liège and Seraing had to cease running. The three new tugs on this line are provided with screws for working down the river without using the rope, as there is very little work to be done in coming down stream. The adoption of the wire-rope navigation has already considerably augmented the traffic on the river, and will no doubt prove still further advantageous when extended to Antwerp in one direction and towards France in the other.

Another important practical illustration of the system is afforded by the case of the top level on the Canal de Charleroi. This level is $6\frac{3}{4}$ miles long, including a tunnel of 1400 yards or more than $\frac{3}{4}$ mile length; and the section of water in the tunnel being only a few inches larger than that of the loaded canal boats, the horses previously employed were $2\frac{1}{2}$ hours in towing the boats through. At the present time one of the wire-rope tugs of 8 horse power and another of 10 horse power are employed, each of which takes a train of from 8 to 10 boats, each of 70 tons burden, through the tunnel in 50 minutes. On the rest of the canal as many as 20 boats

are towed in a single train, notwithstanding the narrow and very crooked nature of the channel. Some of the bends have a radius of not more than 150 yards, and notwithstanding the slow speed that is rendered necessary by the small section of the canal and the bad state of the banks, the tugs steer round the bends with trains of boats in tow having an aggregate displacement fifty times as great as that of the tug itself. The tugs now in use take the place of thirty horses and thirty drivers, and do the work of fifty.

In America the experiments made in wire-rope towing have had reference exclusively to ordinary canal navigation. On most of the Pennsylvania and New York canals, which form by far the most important high roads for the inland traffic of those states, the average distance between the locks is only one mile, and their capacity does not allow of the passage of more than one boat at a time. Under these circumstances the employment of a separate tug or the formation of a train of more than two boats is quite out of the question; and therefore either an engine must be fixed in each separate canal boat, or else portable engines must be used, which at the end of each trip can be shifted on board returning boats, so as to avoid the machinery having to stand idle during the time that the boats are loading and unloading. A 4 horse power portable engine, similar to that already described and shown in Plates 62 and 63, has been working on the Hudson and Delaware Canal at Homsdale, where the channel is very narrow and crooked, and has towed two ordinary canal boats, freighted with 130 tons of coal each, at the rate of $2\frac{1}{2}$ miles an hour, rounding the very sharp bends with perfect ease. This speed is double that attained at present by horse towing; and on the wider and straighter Erie Canal the same engine has towed two 200 ton loaded boats at the speed of $2\frac{3}{4}$ miles an hour, with a consumption of 40 lbs. of coal per hour. The total space occupied by the engine, exclusive of the boiler, is 8 feet length by 4 feet width and 4 feet height, and its weight is altogether $2\frac{1}{4}$ tons; it has a single cylinder 5 inches diameter by 10 inches stroke.

The cost of towing by means of the wire rope and clip drum has been found from the experience of working on the lines at

present in existence to amount to not more than 0·05*d.* ($\frac{1}{20}$th of a penny) per ton per mile, including the whole of the working expenses and management, interest, and redemption of capital. This result is not only another illustration of the great advantage which inland navigation possesses over any other mode of carrying a heavy traffic, where speed is not required; but it also proves the important commercial value of this particular mode of towing as compared with any other methods hitherto in general use. For the average cost of towing by animal power on four English canals—namely the Gloucester and Berkeley, the Monkland, the Forth and Clyde, and the river Lee—amounts to 0·35*d.* per ton per mile; and on seven French canals the average is 0·27*d.* With paddle tugs employed on the Thames the cost of towing was 0·48*d.*, whilst the average cost of towing by the same means on six rivers in France is as high as 0·80*d.* per ton per mile. The employment of screw tugs on three English canals—namely the Gloucester and Berkeley, the Aire and Calder, and the Regent's canal—resulted in an average cost of 0·27*d.*; whilst towing by boats carrying their own machinery cost on seven English canals 0·20*d.* per ton per mile.

The charge made for the wire-rope towing on the Meuse during the regular season is 0·10*d.* per ton per mile for the up traffic, and 0·07*d.* for the down traffic. In winter, owing to the increased currents, it is raised according to the state of the water, the maximum charge being not more than 0·39*d.*, or about the average cost of towing on level canals by other means of traction.

In conclusion it may be remarked that, while railways have undergone so wonderful a development during the past thirty years, the quieter but often more important mode of transporting heavy goods by inland navigation has remained comparatively neglected. It is true that the natural features of this country are not very favourable for inland navigation, although there is in the United Kingdom a total length of 2000 miles of navigable watercourses. But on the Continent, in the Colonies, and especially in India, there is a vast amount of traffic for which no better highways will be found than those already traced by nature in the rivers and streams penetrating the interior of the country.

The system of wire-rope towing that has now been described places inland navigation in a similar relative position to that in which the road traffic was placed by the introduction of the railway and the locomotive. By means of the clip drum the tug obtains a hold upon the flexible rope laid in the watercourse, precisely in the same manner as the driving wheel of the locomotive takes hold of the rigid rail upon which it runs; and the great advantages of steam power may therefore be similarly brought to bear on the movement of vessels in water, leaving to railways all their superiority in regard to speed, but restoring to rivers and canals their advantage in reduction of traction.

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Mr. Eyth exhibited a working model of the clip drum, together with a full-size segment of the rim containing a pair of the clips, and a piece of the wire rope used in towing; and he showed the action of the clips in gripping the rope between them and laying hold of it with a tighter grip under an increased amount of pull upon the rope. He explained that when the clip drum was fixed horizontally, on a vertical axis, the clips all opened in succession as soon as they arrived at the point where the rope quitted the drum, in consequence of the overhanging weight of the lower clip in each pair; a finger on the inner extremity of the lower clip, projecting behind the back of the upper clip, caused the upper clip to be pressed outwards by the lower, so that the two clips moved together in opening for the release of the rope. In a vertical clip drum, every pair of clips round the lower half of the circumference of the drum fell open by the weight of each clip of the pair, as soon as the rope quitted the drum. The necessary amount of grip of the clips was obtained by the application of the small pressing pulley, pressing the tail rope into the jaws of the last pair of clips, at the place where the tail rope passed off slack from the drum of the tug boat without any tension upon it; but this

provision had not been requisite in the previous applications of the clip drum, where the tail rope had in all cases quitted the drum under an amount of tension sufficient to produce grip enough in the clips. He showed also a piece of galvanised wire rope which had recently been cut out of the cable on the River Meuse as a specimen, after a year's service; it looked as good as a new rope, showing no signs of wear. A length of 25 miles on the Meuse had been laid with galvanised iron wire rope, and the remaining length of rope on that river was made of plain iron wire not galvanised, the object of putting down the two sorts of rope being to ascertain which would prove the most durable. Under ordinary circumstances he believed the ungalvanised charcoal iron wire rope was quite sufficient; but in exceptional cases, where the river bed was rocky and rugged, a steel wire rope might be employed with advantage.

Mr. F. J. Bramwell considered the paper just read was a most interesting one, and the subject treated of—the transmission of goods by a cheap mode of conveyance—was unquestionably one of very great importance. Besides the early plans that had been alluded to in the paper for towing barges on canals and rivers, he remembered having seen a steam tug in use upon the Rhone in 1854, fitted in addition to the paddle wheels with a contrivance called a "grappin," which consisted of a vertical wheel armed all round its circumference with a series of spikes shaped like pickaxes; this wheel worked inside a well or hole in the middle of the tug, and was lowered till it reached the bed of the river, along which it then picked its way. When the boat arrived at the end of its journey upstream, the spiked wheel was raised clear of the river bed, and the ordinary paddle wheels were used for going down the river. Another plan which had been employed consisted in having a rail fixed along the bank of the canal above water, instead of a fixed rope lying in the bed of the canal; and a pair of driving wheels, gripping the rail between them, were worked by a steam engine on the tug boat through a driving shaft provided with universal joints; the towing power was thus obtained by means of wheels working above the water instead of below. Both these plans were based on the principle of applying the power by means of some sort of fixed hold, instead of applying it to the

yielding water by paddle wheels or screw propellers. The use of a drum working along a fixed chain had early been applied on a small scale for the "flying bridges" or steam ferry boats employed in several places for crossing rivers; but the crude idea embodied in these limited applications had now been worked out on an extensive scale in the excellent system of traction described in the paper, by the employment of the wire rope in conjunction with the clip drum. The successful manner in which this had been accomplished was no doubt largely due to the advantages afforded by the clip drum; and other prior applications of that simple and ingenious contrivance, to the working of travelling cranes and agricultural implements, had been described at previous meetings of the Institution. Having himself recently witnessed the working of the clip drum in a variety of applications for agricultural and other purposes at the Royal Agricultural Show, he believed it to be an extremely useful contrivance; and it possessed the very important advantage of producing remarkably little wear in the rope working upon it, or in the clips themselves.

The use of portable engines upon the canal barges, as described in the paper, rendering any ordinary barge available as a tug, appeared to have been carried out in a very ingenious manner; and he was particularly struck with the simple arrangement by which the projecting guide pulleys and rope were withdrawn out of the way for passing through a lock, and afterwards restored to their proper position, both movements being effected entirely by the pull of the engine upon the rope. With regard to the steering of a long train of barges in tow, which it had been mentioned in the paper was accomplished with great ease, he presumed it was necessary to have a rudder and steersman to each of the boats in the train, for steering each separately. The indirect pull of the tug upon the rope, owing to the inclination of the rope from a horizontal line, would not be attended, he considered, with any loss of power such as had been referred to in the paper; but the whole power of the engine exerted in the pull upon the rope would be utilised in the horizontal motion of the boat, whatever might be the inclination of the leading rope from the horizontal line. As long as

the tug was standing still, the curves assumed by the leading rope and tail rope would of course be the same; and on starting the engine, the immediate result would be to flatten the curve of the leading rope, raising the rope more towards the horizontal line, and at the same time slackening the tail rope. But when this was once accomplished, the front rope would continue at its new inclination without absorbing any further power from the engine; for it was clear that no more than one mile length of rope passed over the clip drum for one mile advance of the tug, and this being the case it seemed to him an inevitable conclusion that the whole of the power exerted by the engine in the pull upon the rope was realised in the forward motion of the boat; and he did not see therefore that the inclined direction of the leading rope could have the effect of absorbing any portion of the power.

Mr. Eyth remarked that the pull exerted by the engine upon the rope acted in the direction tangential to the curve of the front rope at the point where the rope first touched the leading pulley at the front end of the boat; and as that direction was not horizontal, but slightly inclined to the horizontal line, the force of the pull, when resolved horizontally and vertically, gave a horizontal force nearly but not quite equal to the pull itself, and also a small vertical force. It was the horizontal force alone which could produce the horizontal forward movement of the boat, the vertical force being incapable of producing any horizontal motion whatever; and he considered therefore that this vertical force must constitute a loss of power, forming as it did a constant deduction from the total power exerted by the engine.* That the actual percentage however of the loss due to this source was practically a very insignificant amount was shown by the instance given in the paper of the tug on the river Meuse, where the loss was only 16 lbs. out of the total draft of 4000 lbs. exerted by the engine, being a loss of less than $\frac{1}{2}$ per cent. of the engine power.

He had seen the tug boats on the Rhone that had been referred to, propelled by the spiked wheel or "grappin," and tugs working in that way had been in use for several years on that river. The

* See foot-note on page 254.

great difficulty with them however was the steering, which could not be effected by a rudder, and required the addition of a second spiked wheel, of similar construction to the propelling wheel, but placed with its axis parallel to the centre line of the boat, so as to propel the boat laterally towards either side. On one large tug he had even seen four of these spiked wheels in use, each worked by a separate engine, for the purpose of making the different movements required for propelling and steering the boat. The plan of towing by means of a fixed rail along the canal bank had been tried in America on the Erie Canal; but the great expense of fixing the rail along the whole length of the canal had been considered a serious drawback to its adoption. In towing a train of boats by the wire-rope plan described in the paper, each boat in the train was steered separately by its own boatman, the tug having nothing to do with anything but the towing of the train. On the Canal de Charleroi a long train of as many as twenty boats was towed by a single tug; and in some places on that canal the bends occurred at such short distances that with a train of this length the tug had got beyond the second bend of an S curve before the last boat in the train had entered the first bend. Even in these extreme cases however no difficulty had been experienced in steering all the boats so as to keep the whole length of the train in the centre line of the canal.

Mr. J. Fernie said he had witnessed the early experiments in wire-rope navigation made on the Aire and Calder Canal near Leeds, with a small portable engine and frame placed upon an ordinary canal boat; it was tried at several speeds, and proved from a mechanical point of view a remarkable success, the motion of the boat being in all cases very steady, and the steering was managed with the greatest ease. No account had then been taken of the consumption of fuel, but the results now given in the paper from the working of the lines already in actual operation showed that a very economical means of traction was obtained by this plan, the extended adoption of which he considered was a subject of great importance.

Mr. W. Smith thought the paper was one of much interest as giving the actual results obtained in carrying out in practice this

plan of wire-rope traction. The most important feature in the plan appeared to him to be the application of the clip drum, already so extensively used for agricultural and other purposes; the details of the towing arrangements had been worked out with much ingenuity, particularly the contrivance for withdrawing the projecting framework in passing through locks. The idea of towing boats by means of a submerged wire rope was one of earlier origin, and a series of experiments had been made with this object in 1842 upon a canal in the neighbourhood of London by the late Mr. Andrew Smith, with a wire rope which took a whole turn round a whelp-wheel overhanging the side of the boat, so that the rope could be thrown off for passing other boats or for going through locks. The plan however was not considered to be a commercial success; and the success that had now been arrived at with a similar mode of towing was mainly to be attributed, he thought, to the advantages attending the application of the clip drum in connection with the wire rope. For getting over the difficulties of towing boats through locks, one plan that had been employed for cases where there were a number of locks within a short distance along the canal consisted in providing an endless rope, carried on fixed standards along the side of the canal, and driven by a stationary engine, so that the boats could hitch on and off the rope as required in their passage through the locks; by this means a number of boats were enabled to pass through the locks very rapidly.

Mr. Jeremiah Head remarked that, in reference to the question which had arisen regarding the effect of the inclined direction of pull upon the rope in towing, he concurred in the opinion that the inclination of the rope entailed no loss of power; for as power was made up of two component elements—pressure and motion—a mere continuance of pressure apart from motion did not represent any expenditure of power. Although indeed on first starting the engine the immediate effect would be to depress the boat deeper in the water by the increased strain produced upon the inclined rope, yet as soon as the boat had settled down into its new position it continued in that position during the rest of the time that the engine was at work; and as there was then no further movement

in the vertical direction, the boat not sinking any deeper in the water after first starting, he considered the continuance of the vertical pressure attendant upon the inclination of the rope could not represent any loss of power, beyond the very small increase in resistance due to the increased immersion of the boat. A satisfactory proof that the whole of the engine power was utilised in the horizontal forward motion of the boat was afforded he thought by the consideration which had been mentioned, that for one mile of progress made by the boat exactly one mile length of rope had passed over the clip drum.

Mr. W. Carpmael observed that one source of expenditure of power was the moving of the rope in the vertical direction through the water in lifting it from the bottom.

Mr. W. R. Browne remarked that the inclined direction of the pull had only the effect of increasing the strain upon the rope and the friction upon the bearings of the leading pulley over which it passed at the front of the boat; and after the first depression of the front end of the boat on starting the engine, he considered there would be no loss of power consequent upon the increased pull on the rope, as he was unable to see how any such loss, if it existed, could be accounted for.

Mr. E. A. Cowper fully coincided in the view that no loss of power occurred in consequence of the inclined direction of the pull upon the rope. He also concurred in thinking that the motion of the rope through the water in lifting must be taken into account as a resistance requiring power to overcome it; and although the vertical motion of the rope through the water was exceedingly slow, and the total weight of rope lifted in traversing any distance was theoretically counterbalanced by the weight of rope lowered behind the boat, yet the resistance of the water produced an actual inequality, by increasing the amount of power required to raise the rope in front of the boat, and diminishing the power given out again by the rope descending again to the bottom of the water behind the boat.

Mr. T. Hawksley observed that the mere effort of lifting the rope from the bottom of the water to the top of the clip drum would

involve a very insignificant exertion of power, because in the whole journey the whole length of the rope was simply lifted once through that height. And the effect of the suspended portion of the rope he thought would only be equivalent to an increased load carried by the boat itself; so that if the actual load on the boat were 100 tons and the weight of the suspended rope 1 ton, the effect would be the same as if the total load on the boat were 101 tons. This would increase the immersed midship section less than 1 per cent.; but as the increase would take place only at the top of each side of the section, the skin resistance would be increased in a much smaller proportion, because the bottom surface, where the frictional resistance was the greatest, remained constant under the increased immersion. The inclination of the rope therefore he thought did not enter into the question of the power expended, which might be calculated from the increased load representing the effect of the suspended portion of the rope.

The subject of improving the means of inland navigation, which had been brought forwards in the valuable and interesting paper that had been read, was one with the importance of which he was strongly impressed. The sudden manner in which railways had spread all over the country had he thought diverted the minds of most persons from the consideration of the best mode of improving the existing water navigation, which had consequently been almost entirely neglected. Although there was more water to dispose of for the purposes of inland navigation in England than in most countries, and certainly more than in any continental countries, yet at the present time the canals in this country were practically in the state in which they were left by Brindley eighty or ninety years ago; and notwithstanding the large amount of hydraulic engineering work that had been carried on in the meantime, scarcely any improvements had been made in canal and river navigation. But he was quite satisfied that for slow and heavy traffic canals might advantageously compete with railways. This could not be effected however until canal companies did what railway companies had done, namely provide the means of traffic themselves, and take the haulage into their own hands. It was impossible for the individual

traders using the canals to effect any great improvement in the mode of traffic, while the canals remained unaltered in their present state; nor was it possible for them to establish a system of conducting the traffic, which would require the resources of a powerful company. It was owing he believed to the want of enterprise and joint effort with regard to canal navigation, that so little use was made in this country of one of the best means which nature had provided for effecting a transit from place to place of slow and heavy traffic.

With regard to locks, one of the great obstacles in this country to inland navigation being carried on upon a large scale was that the locks upon the canals and rivers remained exactly as they were at the end of the last century—very narrow, and very short. It would obviously however be quite possible to replace the existing short locks by a sort of skeleton locks, by erecting at frequent intervals along a length of say half a mile detached pieces of masonry containing lockgates, but without any necessity for connecting these to one another from end to end by intervening walls of masonry. Such a plan would allow of taking an entire train of boats of half a mile length through the lock at once, by using only the two gates at the extreme ends of the lock; while a shorter train, or even a single boat only, could be passed through by using some one of the intermediate lockgates, without undue waste of water in comparison with the ordinary locks.

In the working of the tugs mentioned in the paper of from 14 to 20 horse power, he was surprised to learn that high-pressure engines were used, discharging the exhaust steam into the atmosphere or into the water of the canal; and he thought it would have been preferable, with engines of that power, to employ condensing engines so as not to throw away the advantage of the pressure of the atmosphere, especially in countries where coal was not particularly cheap. The adoption of the system of wire-rope navigation now described would afford an excellent opportunity for ascertaining the actual resistance offered by the water to the passage of boats in canals and rivers, which differed so much from the resistance met with in the open sea; and he hoped therefore that this important subject would now be fully investigated, in relation to

the magnitude and shape of the vessels and the other considerations involved in the question.

The PRESIDENT remarked that the clear and elaborate paper now read formed a valuable addition to the proceedings of the Institution; it treated of a subject full of novelty and displaying great practical ingenuity. Whether rope traction had previously been attempted in some similar way was a consideration he thought of no real moment, and nothing new was ever brought forwards without having been in some way foreshadowed. The principle of wire-rope navigation had now been reduced to a practical system, as described in the paper, after a long period spent in improving and maturing it; and he thought it was a matter of congratulation that the beautiful contrivance of the clip drum, without which it appeared the plan would not have been a practical success, had originated in England.

He moved a vote of thanks to Mr. Eyth for his paper, which was passed.

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The PRESIDENT moved a vote of thanks, which was passed, to the Council and Members of the Mining Institute, and the Secretary, Mr. Theo. Wood Bunning, for the cordial welcome they had given to the Members of the Institution, and the important aid they had rendered in the arrangements for the Meeting of the Institution in Newcastle; and to the Directors of the Literary and Philosophical Society for their kindness in granting the free use of the Lecture Theatre for the purposes of the Meeting, and for the facilities they had afforded for the Meeting. Also to the Proprietors of the several Works in Newcastle and the neighbourhood, for the opportunities which they had afforded for the visit to their works by the Members, and the hospitable receptions which had been so

liberally arranged for their accommodation in the Excursions connected with the Meeting; and to the several Railway Companies for the special facilities they had so kindly granted to the Members for attending the Meeting and the Excursions in connection with it.

The Meeting then terminated.

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In the afternoon a number of Engineering and Manufacturing Works in Newcastle and Gateshead and the neighbourhood were visited by the Members.

In the evening the Members were invited by the President to Dinner at his residence, Jesmond Dene, Newcastle.

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On Thursday, 5th August, Excursions were made by the Members to the principal Engineering, Shipbuilding, and Chemical Works &c. on the Tyne, and the River and Pier Works in progress of execution by the Tyne Commissioners.

On Friday Excursions were made by the Members to the Allenheads Lead Works and to the Ironworks and Collieries at Ferryhill and South Brancepeth.

On Saturday the Members were invited by the North Eastern Railway to visit the new Hydraulic Swing Bridge over the River Ouse near Goole, which was seen in operation.

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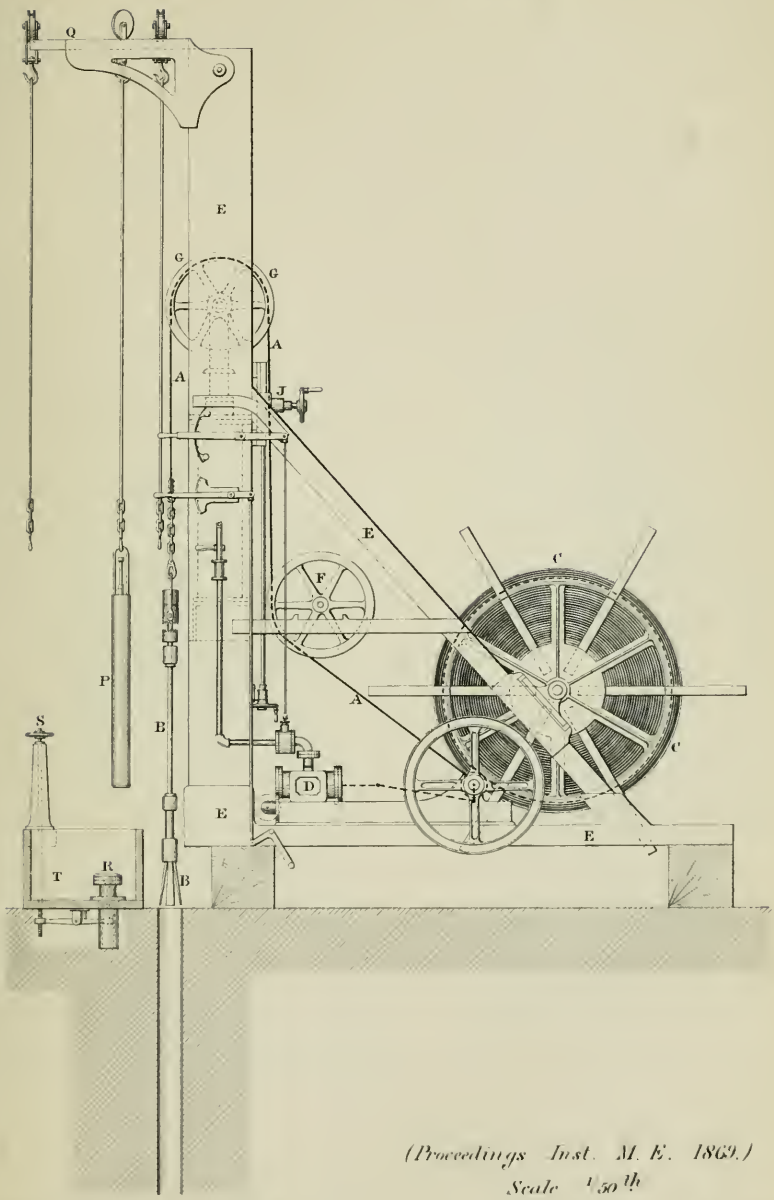
*Small Boring Machine.*

Fig. 1. *Side Elevation.*




*(Proceedings Inst. M. E. 1869.)*

*Scale* 1/50th

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet

*Small Boring Machine.*

Fig. 2. *Front Elevation.*

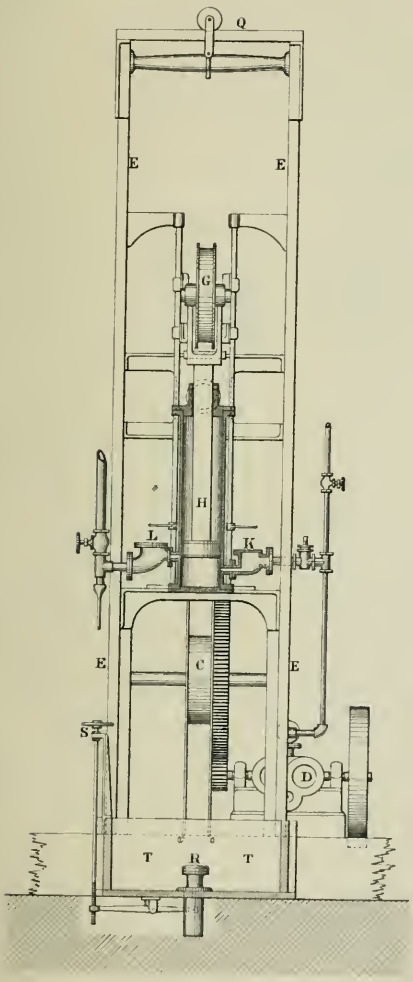
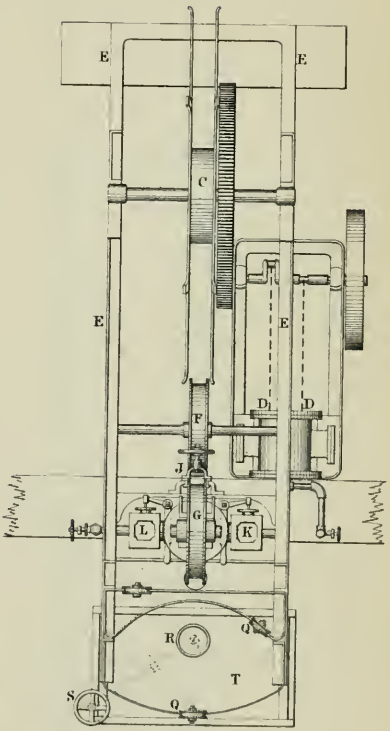



Fig. 3. *Plan.*



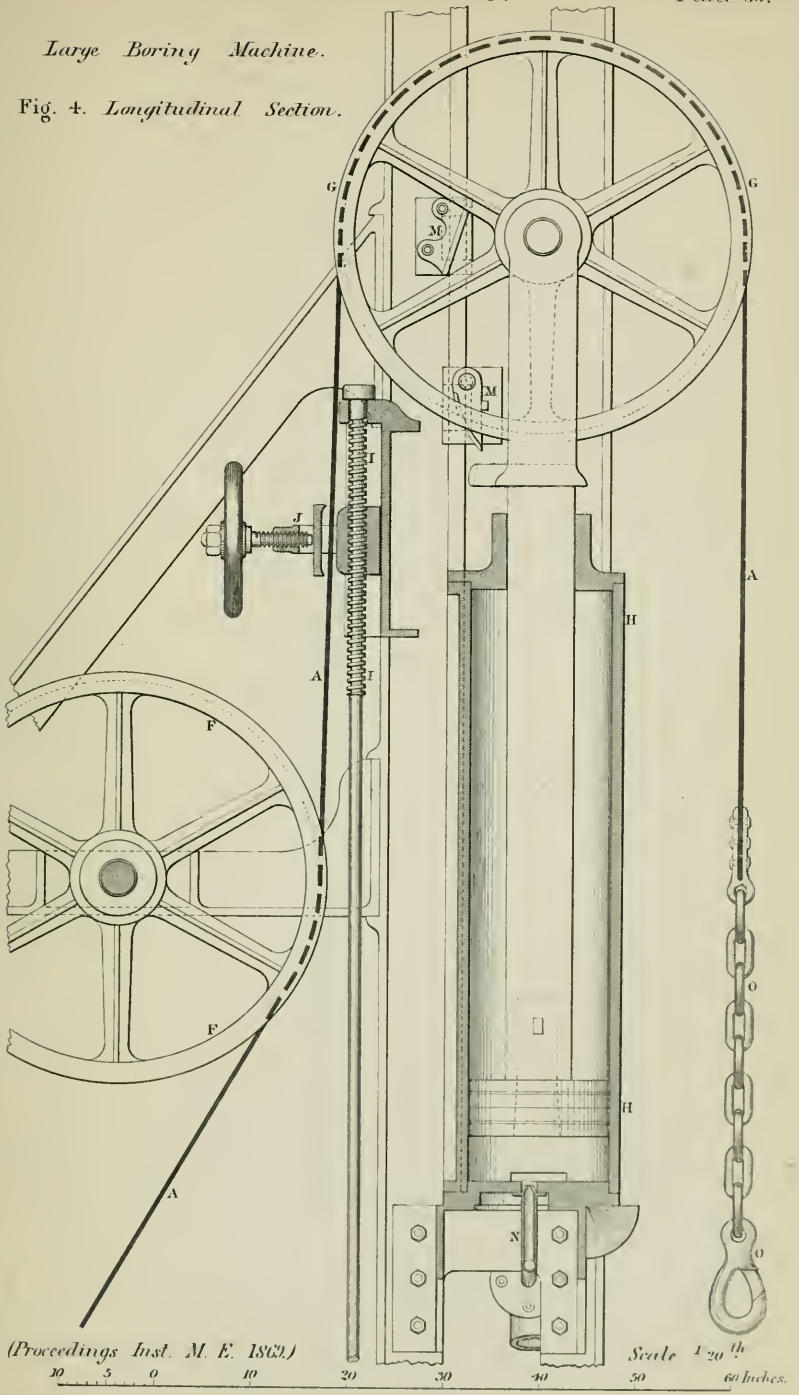

*(Proceedings Inst. M. E. 1869.)*

*Scale* 1/50 th

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 *Feet.*

*Large Boring Machine.*

Fig. 4. *Longitudinal Section.*




*(Proceedings Inst. M. E. 1869.)*

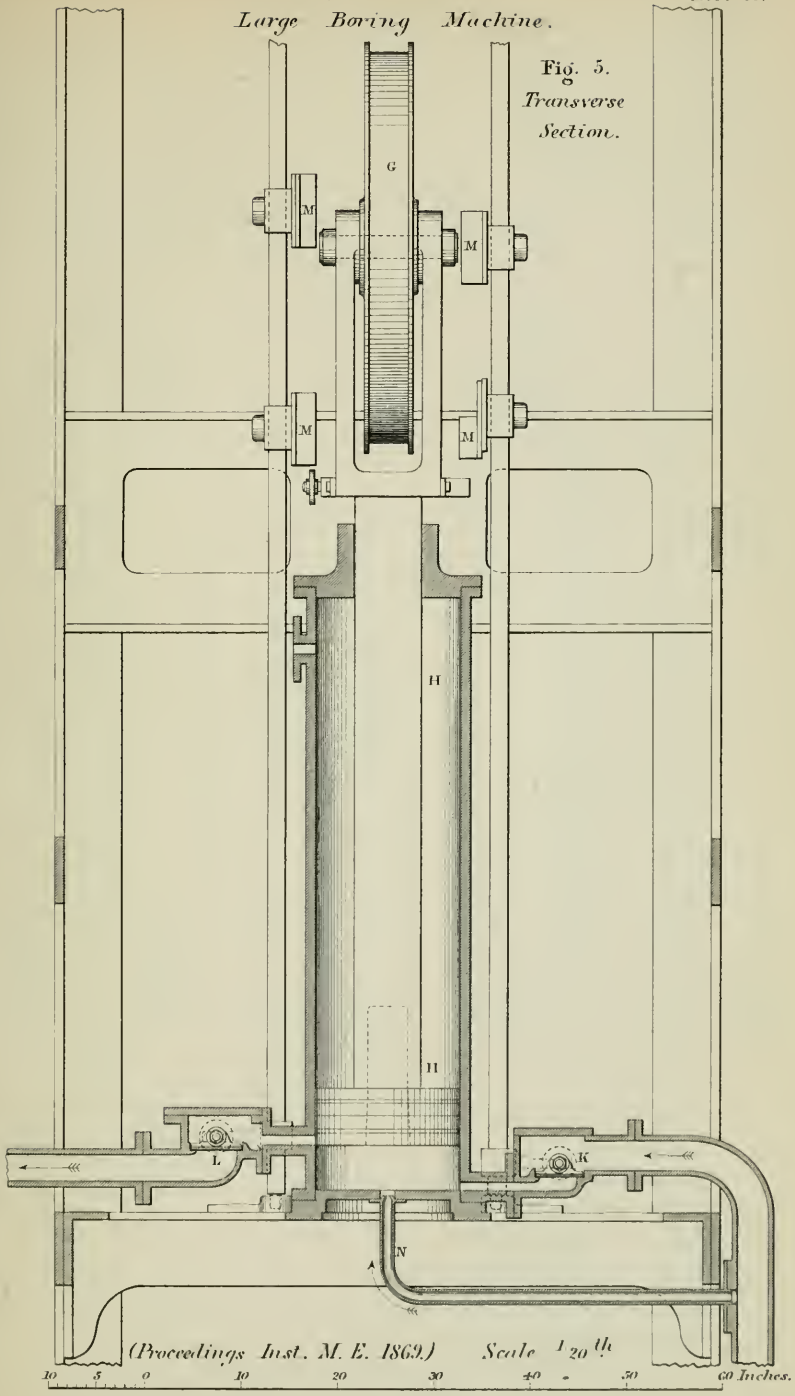
Scale $\frac{1}{20}^{th}$

10 5 0 10 20 30 40 50 60 Inches.

# WELL BORING.

*Plate 69.*

*Large Boring Machine.*



# WELL BORING.



*Boring Head.*

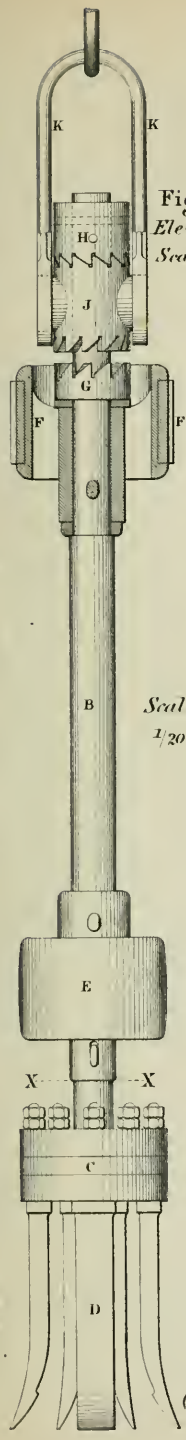



Fig. 6.
*Elevation.*
*Scale 1/20th*

Fig. 7.
*Plan at XX.*

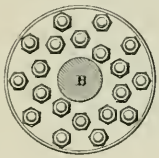
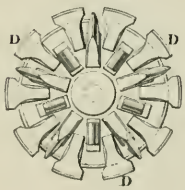



Fig. 8.
*Plan at bottom, inverted.*



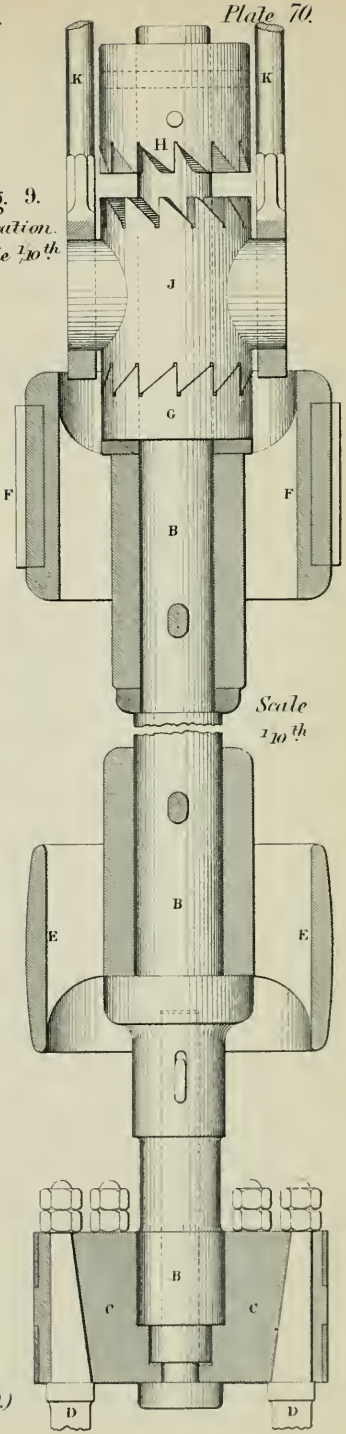




Fig. 9.
*Elevation.*
*Scale 1/10th*

*Scale 1/10th*

*Scale 1/20th*

(Proceedings Inst. M.E. 1869.)

*Shell Pump.*

Fig. 10. *Filling.*

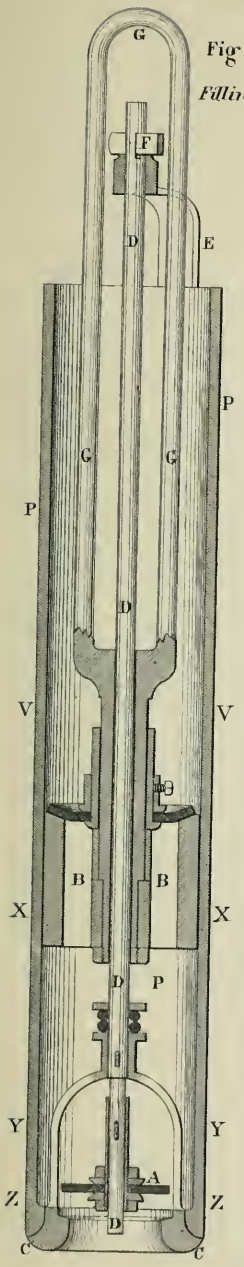



Fig. 12. *Plan at* VV.

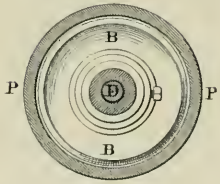



Fig. 13. *Plan at* XX.

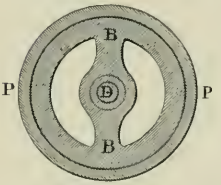



Fig. 14. *Plan at* YY.

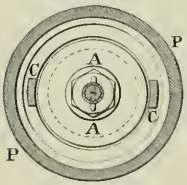



Fig. 15. *Plan at* ZZ.

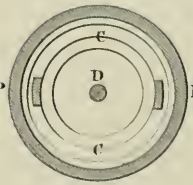
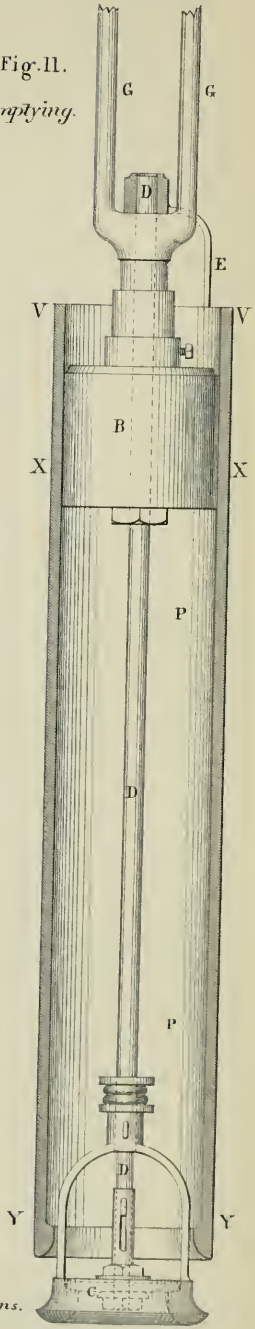



Fig. 11. *Emptying.*




(*Proceedings Inst. M. E. 1869.*)

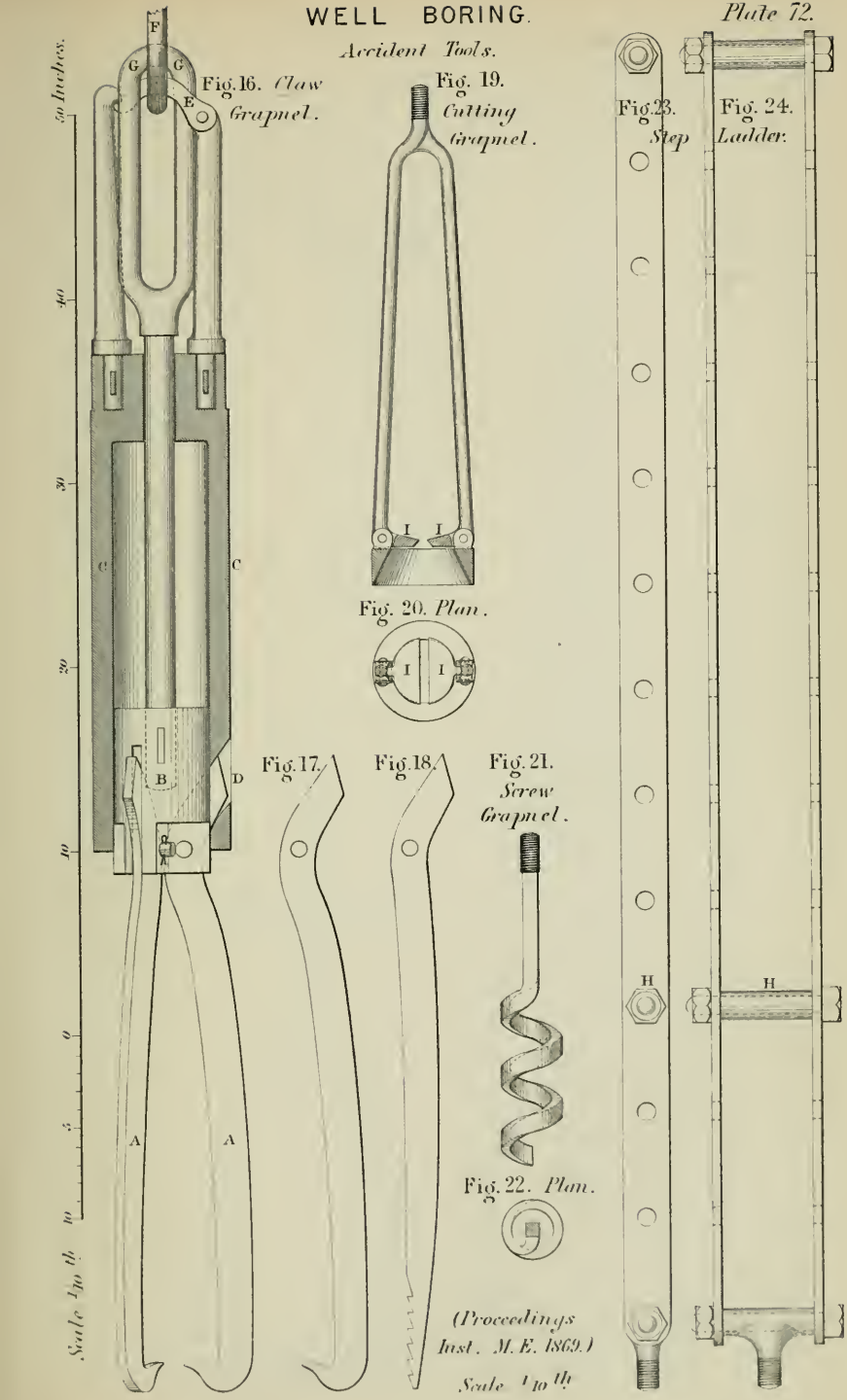
*Scale* 1/14th.

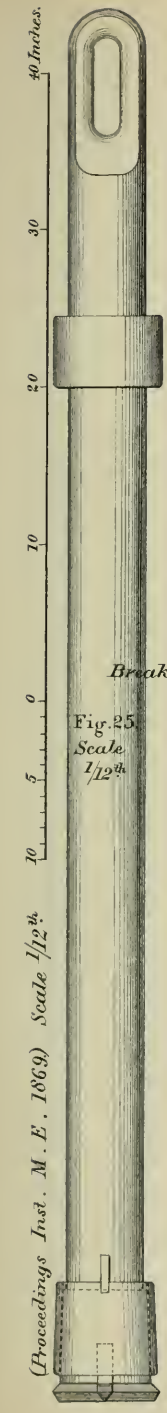
10 5 0 10 20 30 Ins.

# WELL BORING.

*Accident Tools.*

*Plate 72.*

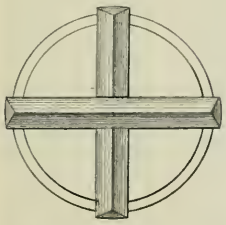




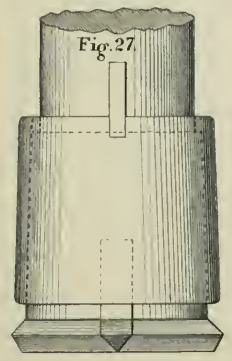

Breaking-up Bar.

Fig. 25.
Scale 1/12th.

Fig. 26.
Plan at bottom, inverted.

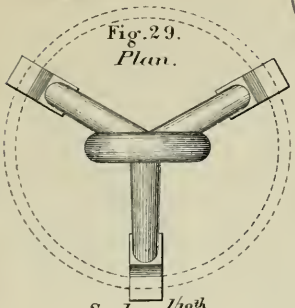


Scale 1/6th.



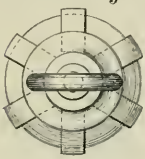

Grapnel for Tubes.

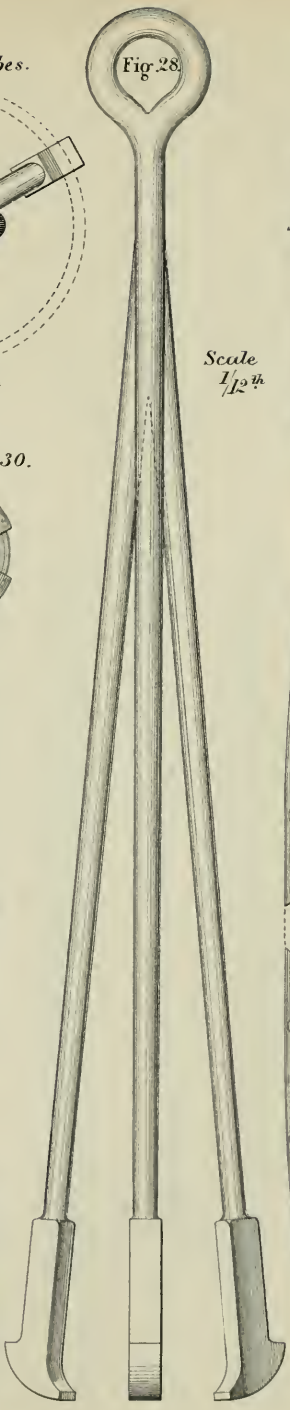
Fig. 29.
Plan.



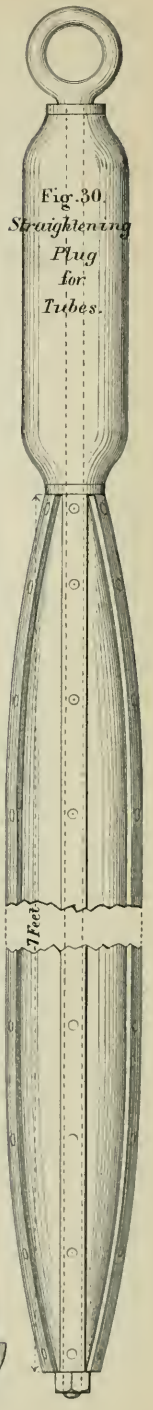
Scale 1/12th.

Fig. 31.
Plan of Fig. 30.






Scale 1/12th.

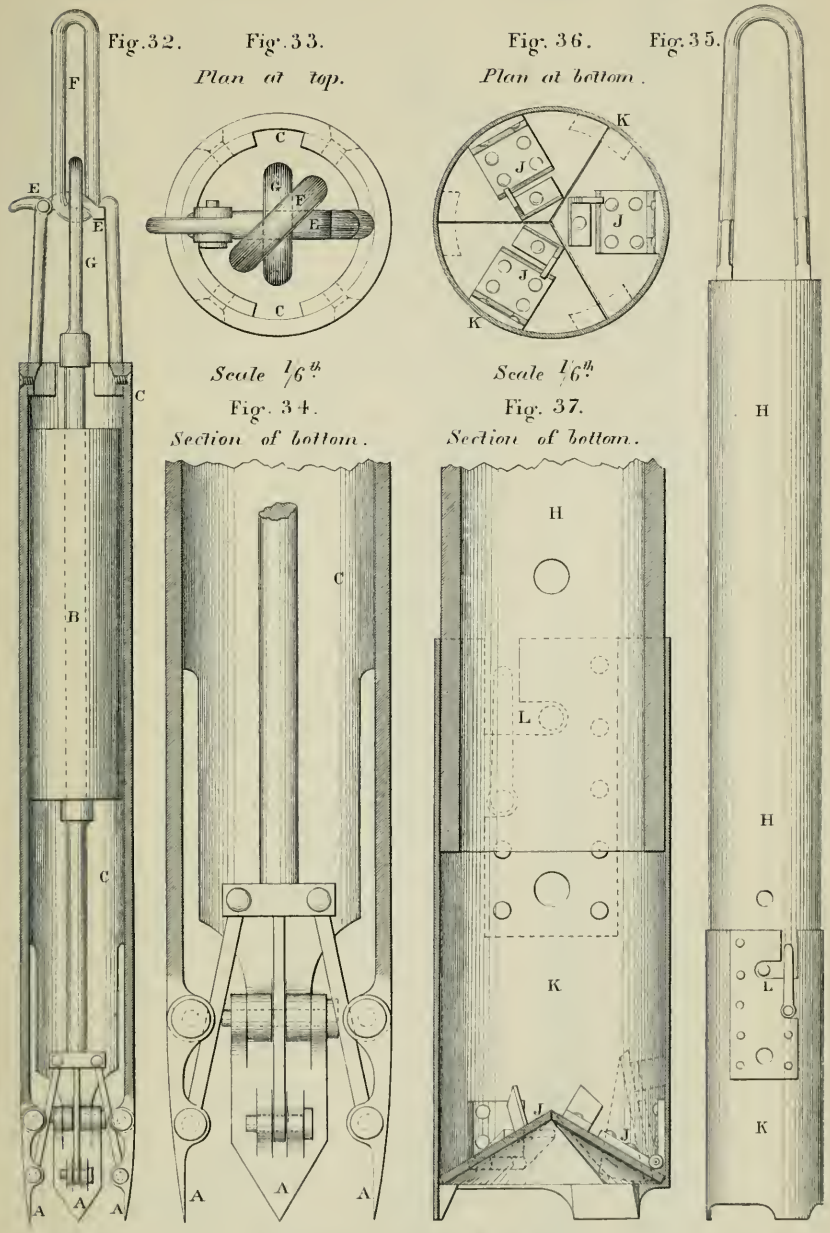



(Proceedings Inst. M. E. 1869) Scale 1/12th.

*Grapnel for Cores.* *Grapnel for Stiff Clay.*

Fig. 32. Fig. 33. Fig. 36. Fig. 35.

*Plan at top.* *Plan at bottom.*




*Scale 1/6th.* *Scale 1/6th.*

Fig. 34. Fig. 37.

*Section of bottom.* *Section of bottom.*

*Scale 1/12th.* *(Proceedings Inst. M. E. 1869.)* *Scale 1/12th.*

10 5 0 10 20 30 Inches.

Fig. 38. *Shell Pump jammed in borehole. Scale 1/16th.*

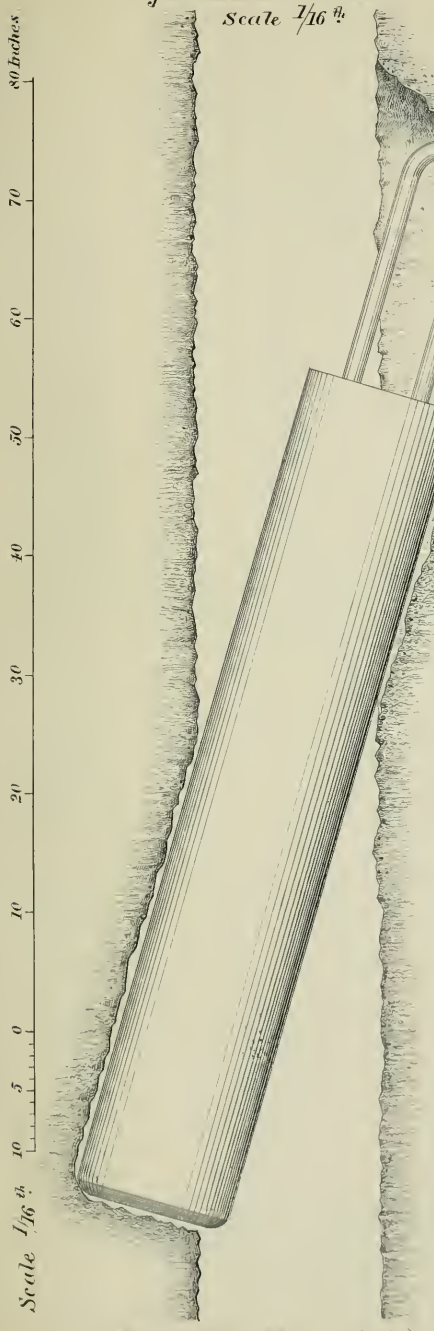



Fig. 39. *Tubing for borehole. Scale 1/16th.*

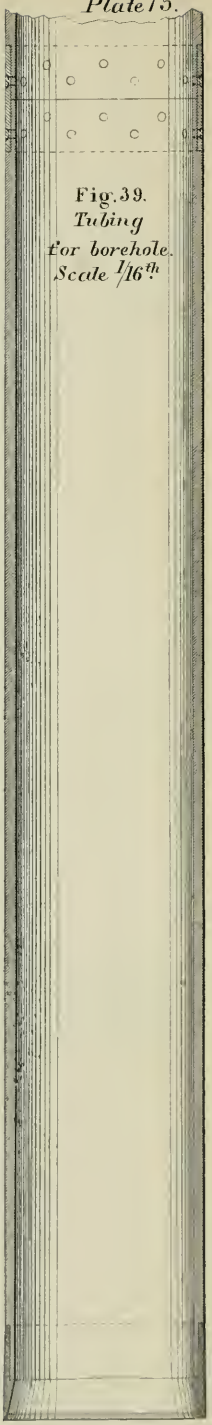


Fig. 40. *Section of Shoe of Tubing. Scale 1/4th.*

(Proceedings Inst. M. E. 1869.)

*Tube-Forcing Apparatus with Screwjacks.*

Fig. 41. *Side Elevation.*

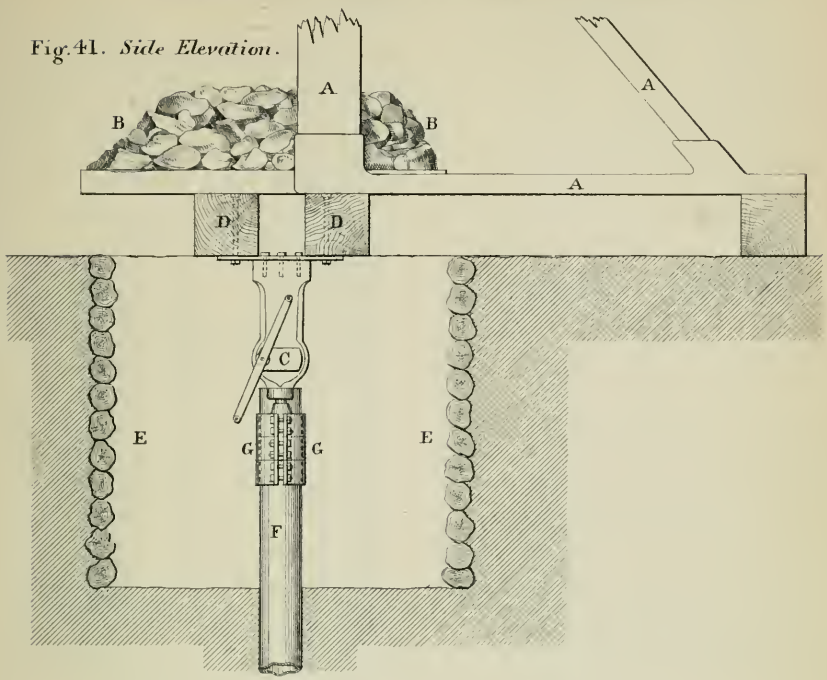
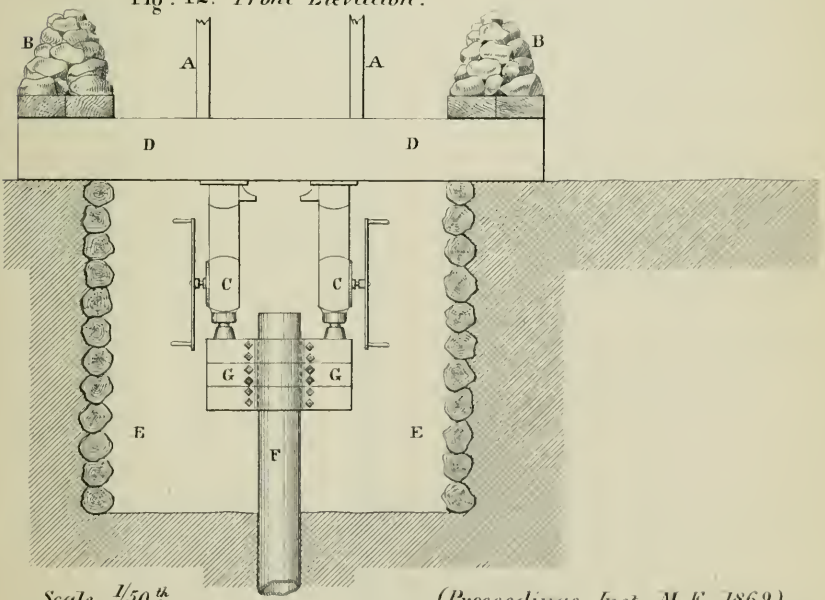



Fig. 42. *Front Elevation.*

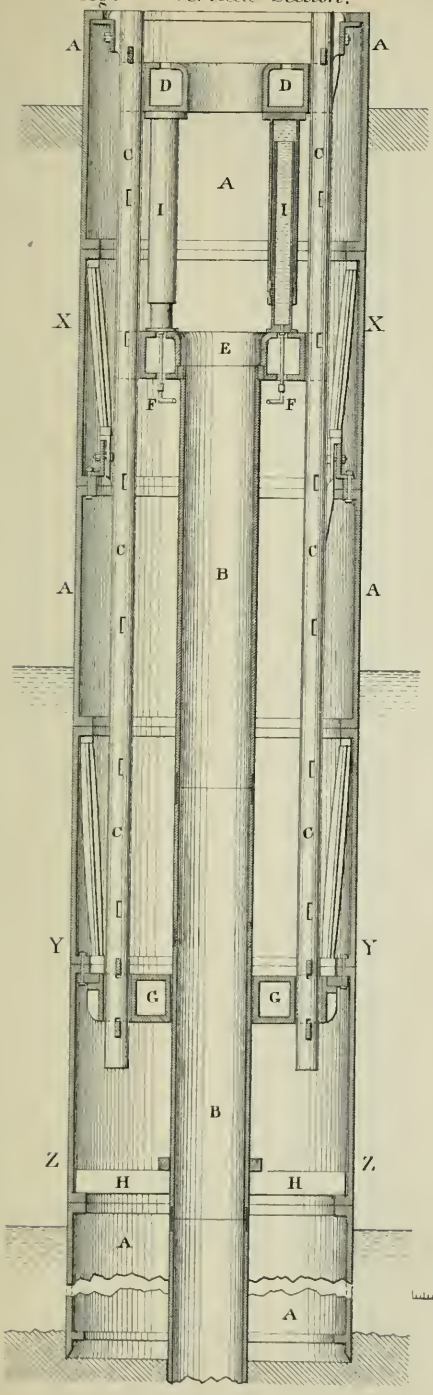



Scale 1/50th

(*Proceedings Inst. M.E. 1869.*)

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

Fig. 43. *Vertical Section.*




*Tube-Forcing Apparatus with Hydraulic Presses.*

Fig. 44. *Plan at* XX.

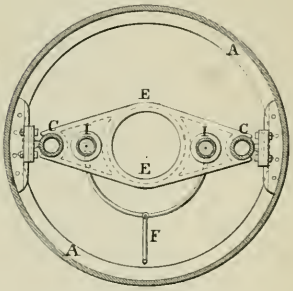



Fig. 45. *Plan at* YY.

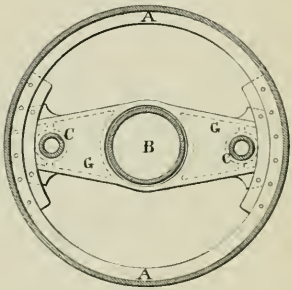
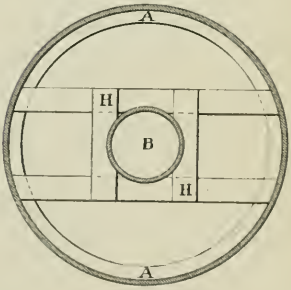
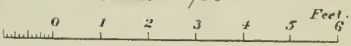



Fig. 46. *Plan at* ZZ.



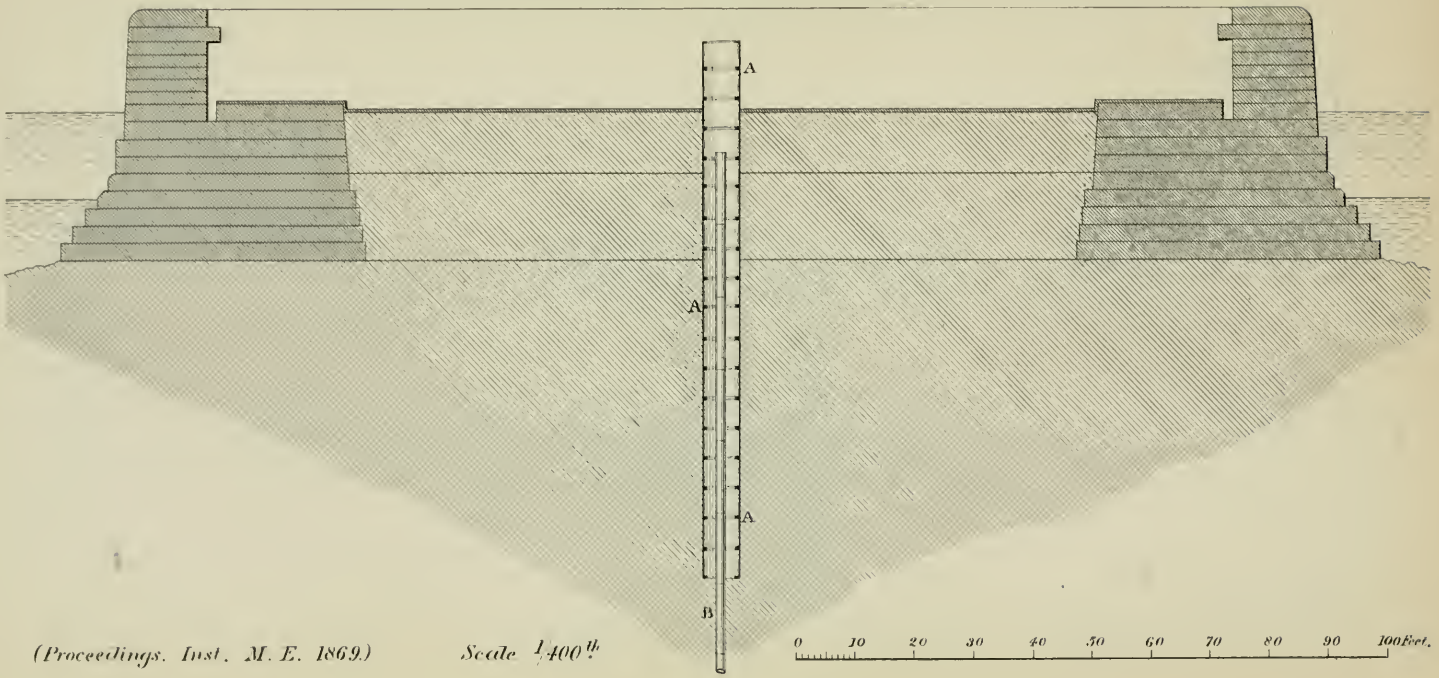

*Scale* 1/50th




(*Proceedings Inst. M.E. 1869.*)

# WELL BORING.

Fig. 47. *Horse Fort, Spithead.*
*Section showing Borehole.*




*(Proceedings. Inst. M. E. 1869.)* *Scale 1/400th*

*Dip Bucket.*

Fig. 48.
*Elevation.*
*Scale 1/12th.*

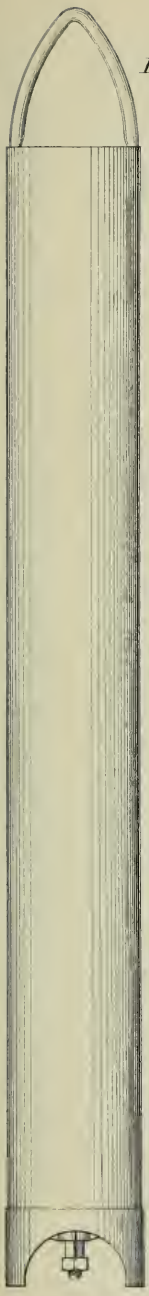


Fig. 49.
*Vertical Section.*
*Scale 1/4th.*

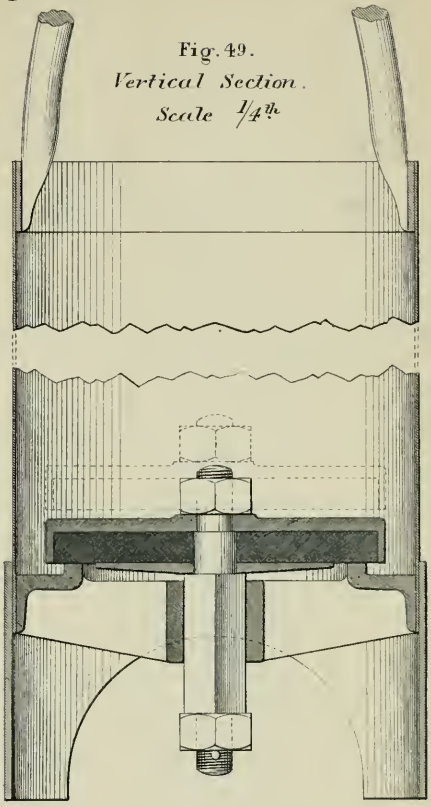
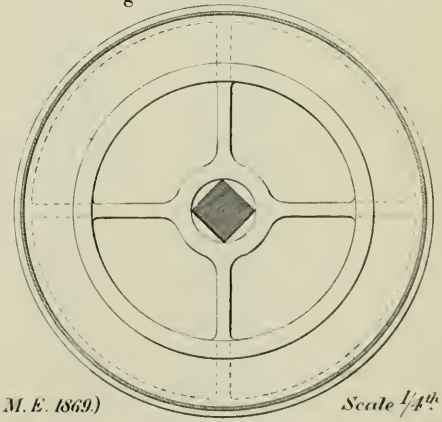


Fig. 50. *Sectional Plan.*



*(Proceedings Inst. M.E. 1869.)*

*Scale 1/4th.*

0 1 2 3 4 5 6 7 8 9 10 Inches

Fig. 51. *Pumping Engine and Borehole.*

*Scale 1/100 th*

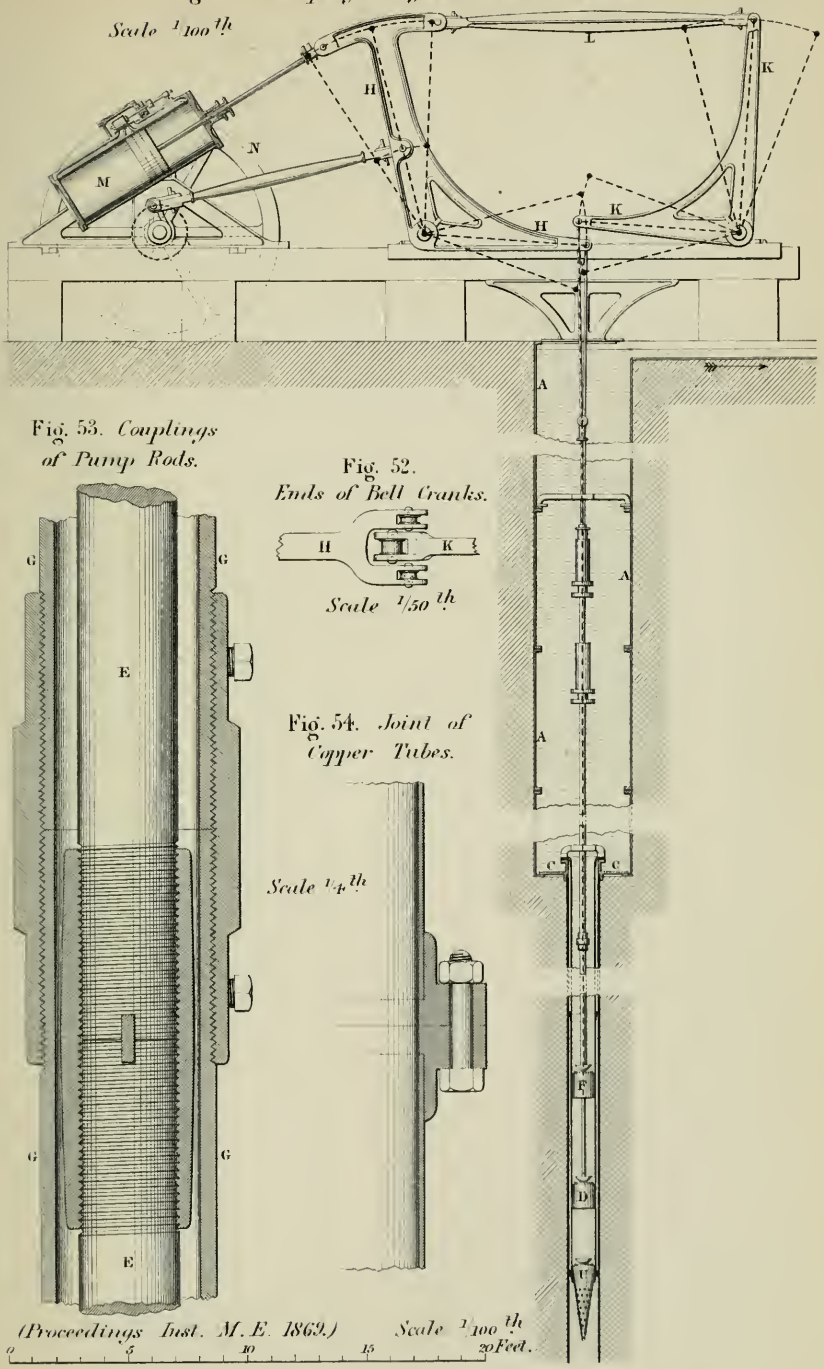



Fig. 53. *Couplings of Pump Rods.*




Fig. 52. *Ends of Bell Cranks.*




*Scale 1/50 th*

Fig. 54. *Joint of Copper Tubes.*



*Scale 1/4 th*

*(Proceedings Inst. M.E. 1869.)*

*Scale 1/100 th*

0 5 10 15 20 Feet.

*Pumping Engine and Double-acting Pump, with improved motion.*

Fig. 55.

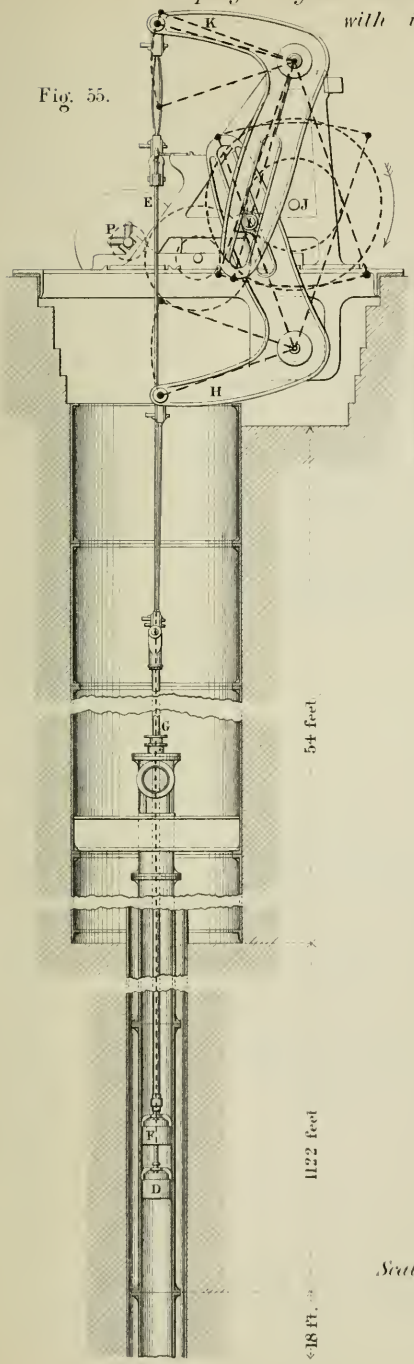
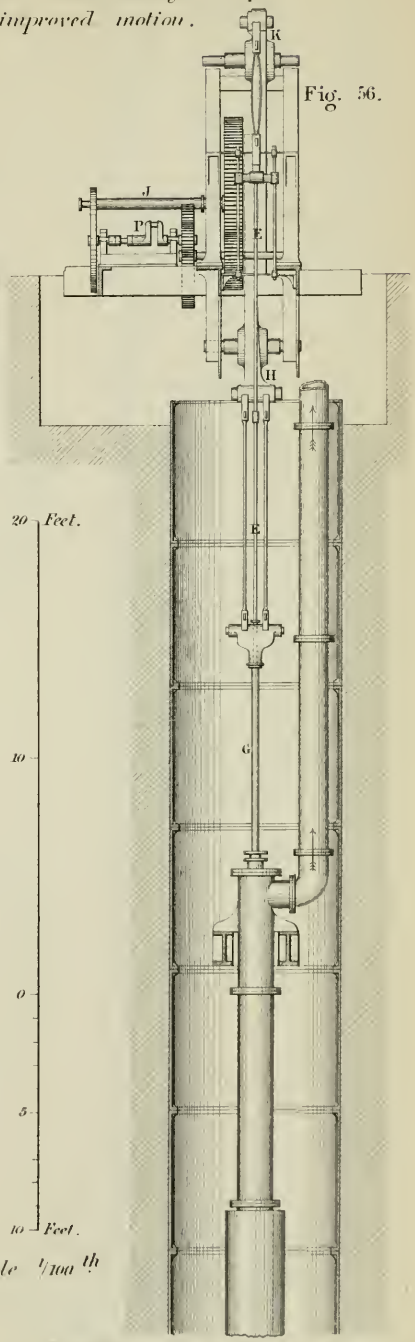



Fig. 56.




(*Proceedings Inst. M. E. 1863.*)

*Double-acting Pump.*

Fig. 57. *Vertical Section. Scale 1/20th*

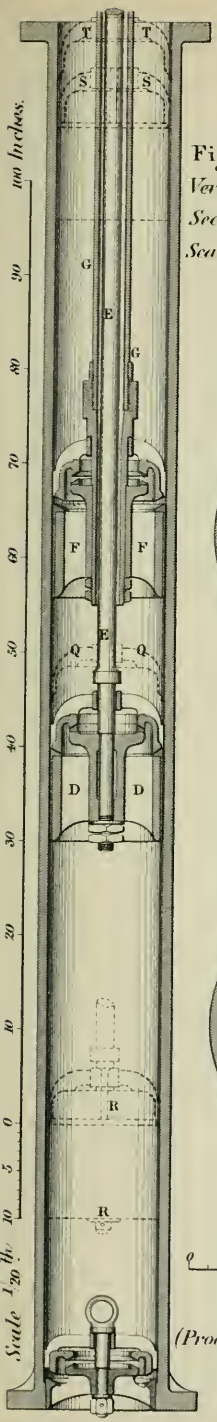



Fig. 58. *Vertical Section. Scale 1/10th*

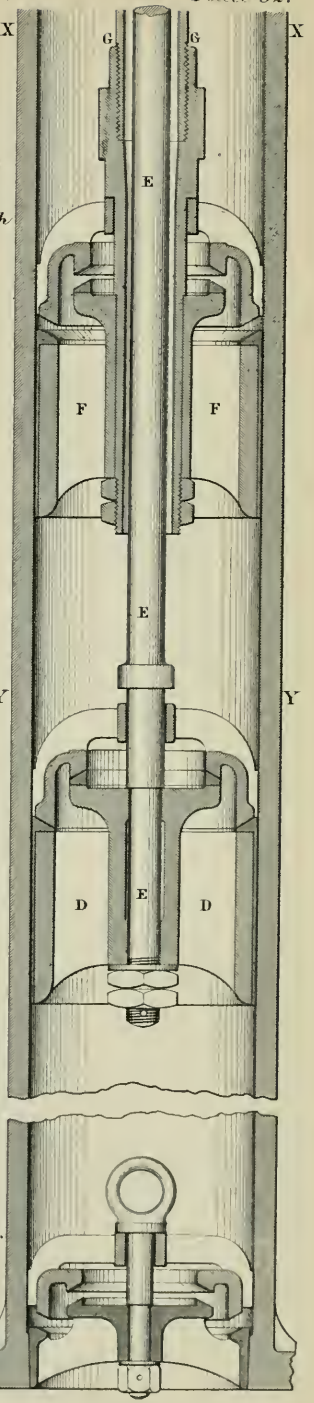



Fig. 59. *Plan at XX.*

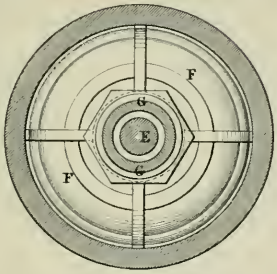
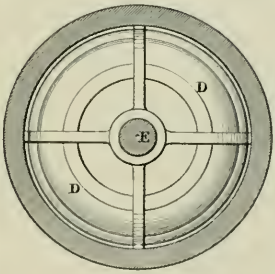
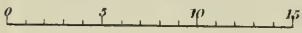



Fig. 60. *Plan at YY.*

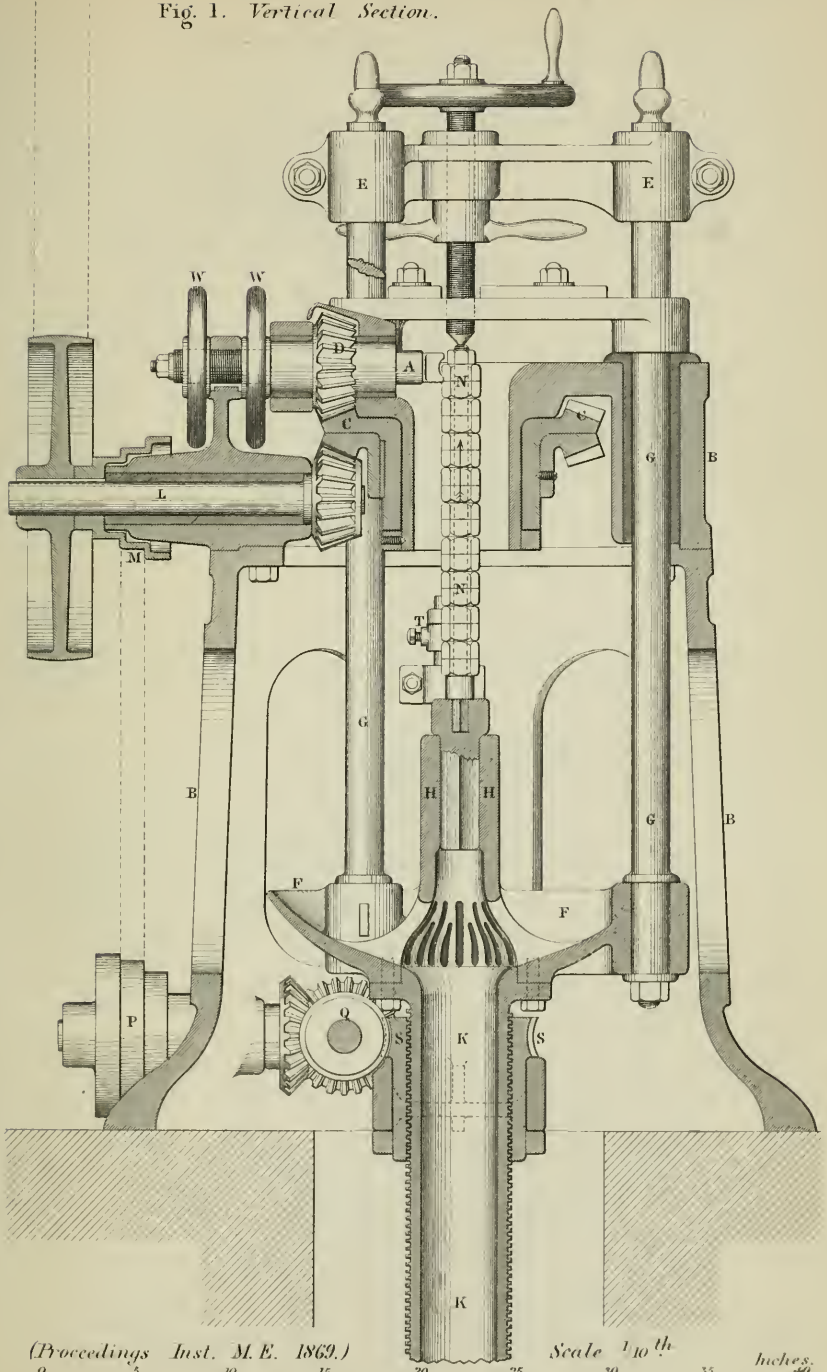



*Scale 1/10 th*




*(Proceedings Inst. M.E. 1869.)*

Fig. 1. *Vertical Section.*




*(Proceedings Inst. M.E. 1869.)* *Scale* 1/10th

0 5 10 15 20 25 30 35 40 *Inches.*

# NUT SHAPING MACHINE.

*Plate 84.*

Fig. 2. *Plan, above cutters.*

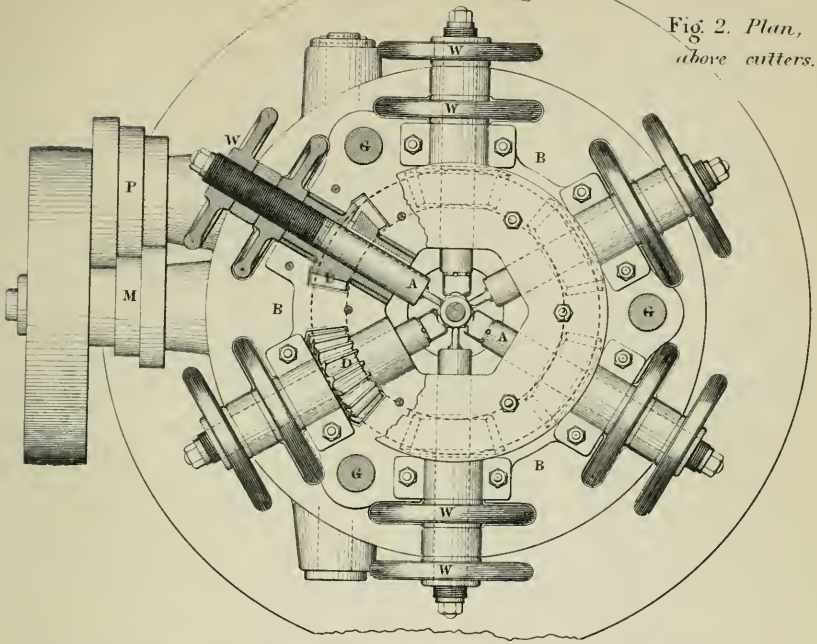
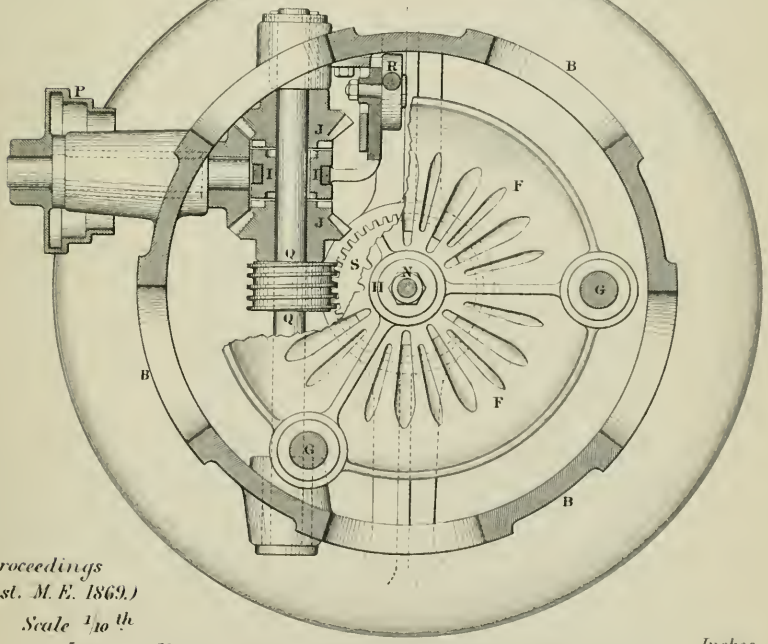



Fig. 3. *Sectional Plan below cutters, showing Feed Motion.*




*(Proceedings Inst. M. E. 1869.)*

*Scale* $^1/_{10}$ *th*

0 5 10 15 20 25 30 35 40 *Inches.*

Fig. 4. *Longitudinal Section of Cutter Spindle and Headstock.*
*Scale* $^1/_5$ *th*

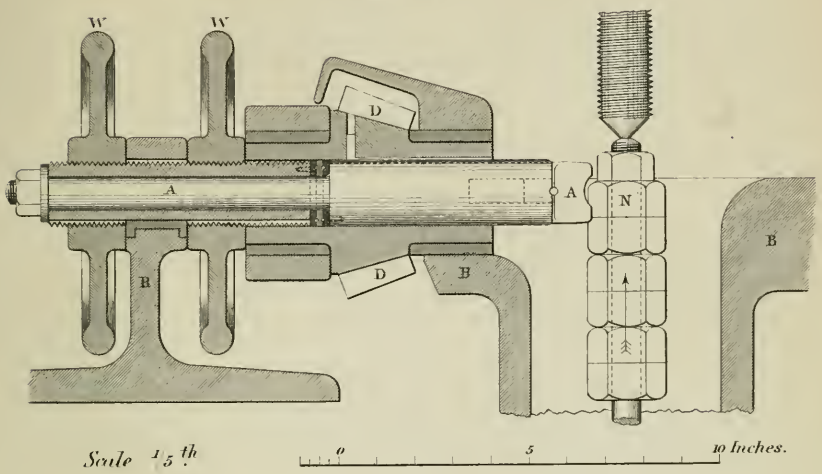
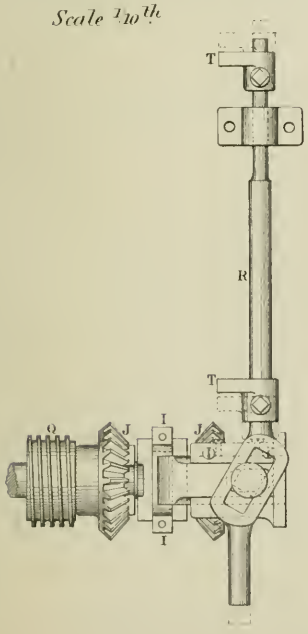



Fig. 5. *Tappet Rod for stopping Feed Motion.*
*Scale* $^1/_{10}$ *th*




*Largest Cutters.*
*Half full size.*

Fig. 6.

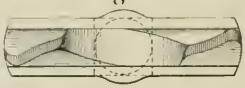
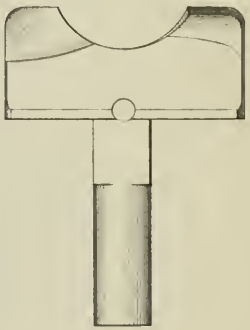


Fig. 8.

Fig. 7.



*(Proceedings Inst. M. E. 1869.)*

# PROCEEDINGS.

4 November, 1869.

The General Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 4th November, 1869; John Ramsbottom, Esq., Vice-President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The Chairman announced that the President, Vice-Presidents, and five Members of the Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Anniversary Meeting.

The following Members were nominated by the meeting for the election at the Anniversary Meeting:—

PRESIDENT.

John Ramsbottom, . . . . Crewe.

VICE-PRESIDENTS.

*(Six of the number to be elected.)*

John Anderson, . . . . Woolwich.
Frederick J. Bramwell, . . London.
Edward A. Cowper, . . . London.
Thomas Hawksley, . . . . London.
Sampson Lloyd, . . . . Wednesbury.
William Menelaus, . . . . Merthyr Tydvil.
John Robinson, . . . . Manchester.
C. William Siemens, . . . London.
Charles P. Stewart, . . . Manchester.

COUNCIL.

(*Six of the number to be elected.*)

| | |
|---|---|
| Charles Edwards Amos, | London. |
| I. Lowthian Bell, | Newcastle-on-Tyne. |
| Peter D. Bennett, | Westbromwich. |
| William Clay, | Birkenhead. |
| Charles Cochrane, | Dudley. |
| Edgar Gilkes, | Middlesbrough. |
| Thomas Greenwood, | Leeds. |
| George Harrison, | Birkenhead. |
| Edward Jones, | Birmingham. |
| Frederick W. Kitson, | Leeds. |
| Richard Williams, | Wednesbury. |

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The Chairman announced that the Ballot Lists had been opened, and the following New Members were duly elected :—

MEMBERS.

| | |
|---|---|
| William Lawson Austin, | Sheffield. |
| Benjamin Giles Bloomer, | Walsall. |
| John Borrie, | Middlesbrough. |
| Benjamin Chapman Browne, | Douglas, Isle-of-Man. |
| John Chadwick, | Manchester. |
| Thomas Clark, | Newcastle-on-Tyne. |
| Louis J. Crossley, | Halifax. |
| William Lawrence Earnshaw, | Folkestone. |
| George Baker Forster, | Newcastle-on-Tyne. |
| Stephen Lancelot Koe, | Bradford. |
| Ralph Peacock, | Manchester. |
| Ralph Peacock, | Goole. |
| Thomas Pickersgill, | Leeds. |
| William Napoleon Rose, | Wednesbury. |
| James Scarlett, | Manchester. |
| James Stabler, | London. |
| Foster Stenson, | Burton-on-Trent. |
| Thomas Sibley Whittem, | Coventry. |

ASSOCIATE.

JOHN JONES, . . . . . Middlesbrough.

GRADUATES.

EMERSON BAINBRIDGE, . . . Newcastle-on-Tyne.
FREDERICK WILLIAM BLAKE, . Birmingham.
CLENNELL FENWICK, . . . . London.
JAMES NIXON GRAINGER, . . Madras.

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The following paper was then read :—

# ON WELL-BORING AND PUMPING MACHINERY.

By Mr. WILLIAM MATHER, of Manchester.

The practice of sinking wells by excavating, for the purpose of obtaining water, is as ancient as any operation on record; the pick, spade, bucket, and windlass, were the tools employed ages ago, and the well-sinker of the present day can boast of little more. But the art of Boring small holes from the surface of the ground, in order to release the pent-up water of porous strata lying at any depth below, is of more recent date. The demand for pure water has increased all over Europe as civilisation has extended and cities have multiplied; and as such development is always accompanied by the pollution of rivers, it has become more and more a necessity to resort to the art of boring wells, in order to obtain an adequate supply of pure water. The mineral resources of all countries have also been heavily taxed during the present century; and this has opened a large field for the operations of sinking shafts.

The first method of Well-Boring known in Europe is that called the Chinese system, in which a chisel suspended by a rope and surrounded by a tube of a few feet length is worked up and down with a jerking motion by means of a spring pole or lever at the surface. The twisting and untwisting of the rope prevent the chisel from always striking in the same place; and by its continued blows the rock is broken and pounded. The chisel is withdrawn occasionally, and a bucket is lowered having a hinged valve at the bottom opening upwards, so that a quantity of the debris becomes enclosed in the bucket and is then drawn up by it to the surface; the lowering of the bucket is repeated until the hole is cleared, and the chisel is then put to work again.

This plan was soon superseded by the substitution of iron or wood rods in place of the rope, and various contrivances in the shape of augers and other tools instead of the simple chisel. In England the spring pole is still largely in use, but the tool is suspended from it by wrought-iron rods in place of the rope. These rods are coupled together in lengths of from 10 to 20 feet by means of screwed couplings, the augers and other tools of various shapes being in like manner screwed to the rods. At each stroke two men at the surface turn the rods slightly, to alter the position of the cutting tool; or if an auger is being used, they continue turning for some time, in order to screw it into the clay or sand. The hole is cleared periodically by raising the rods with a windlass, and uncoupling them at each joint or each alternate joint, and then lowering them all again with a bucket attached at the bottom instead of the cutting tool, the action of the bucket being the same as described above. Innumerable breakages and stoppages occur when a boring is required to be carried to any depth exceeding 200 or 300 feet, owing to the buckling of the rods, the crystallisation of the iron by the constant jarring at each blow, and the increased weight of the rods as the hole gets deeper. To avoid these mishaps a number of most ingenious contrivances have been applied with great success by the French well-borers.

The art of well-boring has received special attention from French engineers. Artesian wells are altogether of French origin, as their name implies; and as the geological formation in many parts of France, especially about Paris, is most favourable to the construction of flowing wells, much experience has led the French engineers to devise many improvements in the boring process. The latest and most perfect system was elaborately explained and illustrated at the meeting of this Institution held in Paris (see Proceedings Inst. M. E. 1867 page 174), showing how the serious difficulty arising from the increasing weight of the rods as the hole became deeper had been met by an arrangement called the "free-falling tool." With this contrivance the force of the blow is given only by the weight of the tool and of a certain portion of the rods, which is accomplished by the lower portion of the rods with the

tool attached being made free to slide in a long slot in the upper portion; so that the rods above do not fall with the tool in giving the blow, and their weight does not affect the force of the blow, which is produced only by the tool falling freely through the length of the slot. The rising and falling motion is obtained by a beam at the surface, to one end of which the rods are attached by a long screw coupling for adjusting their length as the depth of hole increases; at the other end a steam cylinder is placed, by means of which the beam is worked at the requisite number of strokes per minute. When the rods are raised at each stroke, they are turned partially round by a number of men, by means of a horizontal bar passing through an eye immediately below a swivel joint, so that the tool is made to strike in a different place at each time of falling. After the striking motion has been continued some time, the rods which are of wood or iron are drawn up by an engine acting like a steam crane; and when a single length of rod of about 30 feet, or a double length of 60 feet, has been drawn up, the coupling is unscrewed, and the rod removed to one side; the same with the next length, and so on until the tool is brought up out of the hole. The bucket is then attached, and the rods again coupled in succession and lowered; and the bucket sinking in the debris at the bottom of the hole encloses a quantity of it by means of the foot-valve, and is then brought up again to the surface by raising and uncoupling the rods as before. A very extensive variety of tools, augers, and buckets, were exhibited, which were stated to be required for boring through the different strata met with; and the wrought-iron and copper tubes were also shown, which had to be inserted in unstable or soft strata.

In addition to the cases mentioned at the Paris meeting, the writer has had frequent opportunity of witnessing this system of boring in operation elsewhere. In the neighbourhood of Moscow a trial was made for coal a few years ago, by a boring 12 inches diameter carried to a depth of 900 feet, which occupied two years and cost about £4000. At the present time a boring is being put down in Moscow with the view of reaching water-bearing strata, which it is supposed will be met with at 3000 feet depth capable of

supplying water to the surface in ample quantity for the use of the city. This boring, which the writer has seen in operation, has now been nearly three years in progress; the diameter is 3 feet at the top, and is reduced to 18 inches at the depth now reached of 1070 feet; there are fifteen men constantly employed, and the work is carried on for the most part night and day. Although as regards diameter, depth, and flow of water in favourable localities, some extraordinary results have been obtained with the system of boring by rods worked by steam power, yet, as the writer of the paper read at the Paris meeting observed, "in some instances his own experience of boring had been, that owing to the difficulties attending the operation, the occurrence of delays from accidents was the rule, while the regular working of the machinery was the exception." A further disadvantage to be noticed is that, owing to the time and labour involved in raising and lowering heavy rods in borings of 10 inches diameter and upwards, there is a strong inducement to keep the boring tool at work for a much longer period than is actually necessary for breaking up fresh material at each stroke. The fact is that after from 100 to 200 blows have been given, the boring tool merely falls into the accumulated debris and pounds this into dust, without again touching the surface of the solid rock. It may therefore be easily understood how much time is totally lost out of the periods of five to eight hours during which with the rod system the tool is allowed to continue working. These circumstances account for the enormous cost of many of the artesian wells on the Continent, and also for the limited use of boring as a test for minerals at great depths.

In the most recent method of boring adopted in England, the rope employed in the Chinese system has been reverted to, in place of the iron or wood rods used on the Continent. A flexible rope admits of being handled with greater facility than iron rods, but wants the advantage of rigidity: in the Chinese method it admitted of withdrawing the chisel or bucket very rapidly, but gave no certainty to the operation of the chisel at the bottom of the hole. The rods on the other hand enable a very effective blow to be given, with a definite turning or screwing motion between the blows

according to the requirements of the strata; but the time and trouble of raising heavy rods from great depths on each occasion of changing from boring to clearing out the hole form a serious drawback, which makes the stoppages occupy really a longer time than the actual working of the machinery.

The method of Boring that forms the subject of the present paper, which has been invented by Mr. Colin Mather, a relative of the writer, and has been employed largely in England by the writer's firm, seems to combine the advantages of all the systems hitherto used, and to be free from many of their disadvantages. The distinctive features of this plan, which is shown in the accompanying Plates 66 to 82, are the mode of giving the percussive action to the boring tool, and the construction of the tool or boring-head, and of the shell-pump for clearing out the hole after the action of the boring-head. Instead of these implements being attached to rods, as in the previous system, they are suspended by a flat hemp rope, about $\frac{1}{2}$ inch thick and $4\frac{1}{2}$ inches broad, such as is commonly used at collieries; and the boring tool and shell-pump are raised and lowered as quickly in the borehole as the bucket and cages in a colliery shaft.

The flat rope A A, Fig. 1, Plate 66, from which the boring-head B is suspended, is wound upon a large drum C driven by a steam engine D with a reversing motion, so that one man can regulate the operation with the greatest ease. All the working parts are fitted into a wood or iron framing E E, rendering the whole a compact and complete machine. On leaving the drum C the rope passes under a guide pulley F, and then over a large pulley G carried in a fork at the top of the piston-rod of a vertical single-acting steam cylinder H.

This cylinder, by which the Percussive Action of the boring-head is produced, is shown to a larger scale in the vertical sections, Figs. 4 and 5, Plates 68 and 69; in the larger size of machine here shown, the cylinder is fitted with a piston of 15 inches diameter, having a heavy cast-iron rod 7 inches square, which is made with a fork at the top carrying the flanged pulley G of about 3 feet diameter and

of sufficient breadth for the flat rope A to pass over it. The boring-head having been lowered by the winding drum to the bottom of the borehole, the rope is fixed secure at that length by the clamp J; steam is then admitted underneath the piston in the cylinder H by the steam valve K, and the boring tool is lifted by the ascent of the piston-rod and pulley G; and on arriving at the top of the stroke the exhaust valve L is opened for the steam to escape, allowing the piston-rod and carrying pulley to fall freely with the boring tool, which falls with its full weight to the bottom of the borehole. The exhaust port is 6 inches above the bottom of the cylinder, while the steam port is situated at the bottom; and there is thus always an elastic cushion of steam retained in the cylinder of that thickness for the piston to fall upon, preventing the piston from striking the bottom of the cylinder. The steam and exhaust valves are worked with a self-acting motion by the tappets M M, which are actuated by the movement of the piston-rod; and a rapid succession of blows is thus given by the boring tool on the bottom of the borehole. As it is necessary that motion should be given to the piston before the valves can be acted upon, a small jet of steam N is allowed to be constantly blowing into the bottom of the cylinder; this causes the piston to move slowly at first, so as to take up the slack of the rope and allow it to receive the weight of the boring-head gradually and without a jerk. An arm attached to the piston-rod then comes in contact with a tappet which opens the steam valve K, and the piston rises quickly to the top of the stroke; another tappet worked by the same arm then shuts off the steam, and the exhaust valve L is opened by a corresponding arrangement on the opposite side of the piston-rod, as shown in Fig. 5. By shifting these tappets the length of stroke of the piston can be varied from 1 to 8 feet in the large machine, according to the material to be bored through; and the height of fall of the boring-head at the bottom of the borehole is double the length of stroke of the piston. The fall of the boring-head and piston can also be regulated by a weighted valve on the exhaust pipe, checking the escape of the steam, so as to cause the descent to take place slowly or quickly as may be desired.

The Boring-Head B, Fig. 1, is shown to a larger scale in Figs. 6 to 9, Plate 70, and consists of a wrought-iron bar about 4 inches diameter and 8 feet long, to the bottom of which a cast-iron cylindrical block C is secured. This block has numerous square holes through it, into which the chisels or cutters D D are inserted with taper shanks, as shown in Fig. 9, so as to be very firm when working, but to be readily taken out for repairing and sharpening; two different arrangements of the cutters are shown in the elevation, Fig. 6, and the plan, Fig. 8. A little above the block C another cylindrical casting E is fixed upon the bar B, which acts simply as a guide to keep the bar perpendicular. Higher still is fixed a second guide F, but on the circumference of this are secured cast-iron plates made with ribs of a saw-tooth or ratchet shape, catching only in one direction; these ribs are placed at an inclination like segments of a screw thread of very long pitch, so that as they bear against the rough sides of the borehole when the bar is raised or lowered they assist in turning it, for causing the cutters to strike in a fresh place at each stroke. Each alternate plate has the projecting ribs inclined in the opposite direction, so that one half of the ribs are acting to turn the bar round in rising, and the other half to turn it in the same direction in falling. These projecting spiral ribs simply assist in turning the bar, and immediately above the upper guide F is the arrangement by which the definite rotation is secured. To effect this object two cast-iron collars G and H are cottered fast to the top of the bar B, and placed about 12 inches apart; the upper face of the lower collar G is formed with deep ratchet-teeth of about 2 inches pitch, and the under face of the top collar H is formed with similar ratchet-teeth, set exactly in line with those on the lower collar. Between these collars and sliding freely on the neck of the boring bar B is a deep bush J, which is also formed with corresponding ratchet-teeth on both its upper and lower faces; but the teeth on the upper face are set half a tooth in advance of those on the lower face, so that the perpendicular side of each tooth on the upper face of the bush is directly above the centre of the inclined side of a tooth on the lower face. To this bush is attached the wrought-iron bow K, by which

the whole boring bar is suspended with a hook and shackle O, Fig. 4, from the end of the flat rope A. The rotary motion of the bar is obtained as follows: when the boring tool falls and strikes the blow, the lifting bush J, which during the lifting has been engaged with the ratchet-teeth of the top collar H, falls upon those of the bottom collar G, and thereby receives a twist backwards through the space of half a tooth; and on commencing to lift again, the bush rising up against the ratchet-teeth of the top collar H receives a further twist backwards through half a tooth. The flat rope is thus twisted backwards to the extent of one tooth of the ratchet; and during the lifting of the tool it untwists itself again, thereby rotating the boring tool forwards through that extent of twist between each successive blow of the tool. The amount of the rotation may be varied by making the ratchet-teeth of coarser or finer pitch. The motion is entirely self-acting, and the rotary movement of the boring tool is ensured with mechanical accuracy. This simple and most effective action taking place at every blow of the tool produces a constant change in the position of the cutters, thus increasing their effect in breaking the rock.

The Shell-Pump, for raising the material broken up by the boring-head, is shown in Figs. 10 to 15, Plate 71, and consists of a cylindrical shell or barrel P of cast-iron, about 8 feet long and a little smaller in diameter than the size of the borehole. At the bottom is a clack A opening upwards, somewhat similar to that in ordinary pumps; but its seating, instead of being fastened to the cylinder P, is in an annular frame C, which is held up against the bottom of the cylinder by a rod D passing up to a wrought-iron bridge E at the top, where it is secured by a cotter F. Inside the cylinder works a bucket B, similar to that of a common lift-pump, having an india-rubber disc valve on the top side; and the rod D of the bottom clack passes freely through the bucket. The rod G of the bucket itself is formed like a long link in a chain, and by this link the pump is suspended from the shackle O, Fig. 4, at the end of the flat rope, the bridge E, Fig. 11, preventing the bucket from being drawn out of the cylinder. The bottom clack A is made with an india-rubber disc, which opens sufficiently to allow the

water and smaller particles of stone to enter the cylinder; and in order to enable the pieces of broken rock to be brought up as large as possible, the entire clack is free to rise bodily about 6 inches from the annular frame C, as shown in Fig. 10, thereby affording ample space for large pieces of rock to enter the cylinder, when drawn in by the upstroke of the bucket.

The general working of the boring machine is as follows. The winding drum C, Fig. 1, Plate 66, is 10 feet diameter in the large machine, and is capable of holding 3000 feet length of rope $4\frac{1}{2}$ inches broad and $\frac{1}{2}$ inch thick. When the boring-head B is hooked on the shackle at the end of the rope A, its weight pulls round the drum and winding engine, and by means of a break it is lowered steadily to the bottom of the borehole; the rope is then secured at that length by screwing up tight the clamp J. The small steam jet N, Figs. 4 and 5, is next turned on, for starting the working of the percussion cylinder H; and the boring-head is then kept continuously at work until it has broken up a sufficient quantity of material at the bottom of the borehole. The clamp J which grips the rope is made with a slide and screw I, Fig. 4, whereby more rope can be gradually given out as the boring-head penetrates deeper in the hole. In order to increase the lift of the boring-head, or to compensate for the elastic stretching of the rope, which is found to amount to 1 inch in each 100 feet length, it is simply necessary to raise the top pair of tappets on the tappet rods whilst the percussive motion is in operation. When the boring-head has been kept at work long enough, the steam is shut off from the percussion cylinder, the rope unclamped, the winding engine put in motion, and the boring-head wound up to the surface, where it is then slung from an overhead suspension bar Q, Fig. 1, by means of a hook mounted on a roller for running the boring-head away to one side, clear of the borehole.

The shell-pump is next lowered down the borehole by the rope, and the debris pumped into it by lowering and raising the bucket about three times at the bottom of the hole, which is readily effected by means of the reversing motion of the winding engine. The pump

is then brought up to the surface, and emptied by the following very simple arrangement: it is slung by a traversing hook from the overhead suspension bar Q, Fig. 1, and is brought perpendicularly over a small table R in the waste tank T; and the table is raised by the screw S until it receives the weight of the pump. The cotter F, Fig. 10, which holds up the clack seating C at the bottom of the pump, is then knocked out; and the table being lowered by the screw, the whole clack seating C descends with it, as shown in Fig. 11, and the contents of the pump are washed out by the rush of water contained in the pump cylinder. The table is then raised again by the screw, replacing the clack seating in its proper position, in which it is secured by driving the cotter F into the slot at the top; and the pump is again ready to be lowered down the borehole as before. It is sometimes necessary for the pump to be emptied and lowered three or four times in order to remove all the material that has been broken up by the boring-head at one operation.

The rapidity with which these operations may be carried on is found in the experience of the working of the machine to be as follows. The boring-head is lowered at the rate of 500 feet per minute. The percussive motion gives 24 blows per minute; this rate of working continued for about 10 minutes in red sandstone and similar strata is sufficient for enabling the cutters to penetrate about 6 inches depth, when the boring-head is wound up again at the rate of 300 feet per minute. The shell-pump is lowered and raised at the same speeds, but only remains down about 2 minutes; and the emptying of the pump when drawn up occupies about 2 or 3 minutes.

In the construction of this machine it will be seen that the great desideratum of all earth boring has been well kept in view: namely to bore holes of large diameter to great depths with rapidity and safety. The object is to keep either the boring-head or the shell-pump constantly at work at the bottom of the borehole, where the actual work has to be done; to lose as little time as possible in raising, lowering, and changing the tools, &c.; to expedite all the operations at the surface; and to economise manual labour in every particular. With this machine, one man standing

on a platform at the side of the percussion cylinder performs all the operations of raising and lowering by the winding engine, changing the boring-head and shell-pump, regulating the percussive action, and clamping or unclamping the rope: all the handles for the various steam valves are close to his hand, and the break for lowering is worked by his foot. Two labourers attend to changing the cutters, and clearing the pump. Duplicate boring-heads and pumps are slung to the overhead suspension bar Q, Fig. 1, ready for use, thus avoiding all delay when any change is requisite.

The practical value of this plan of well boring is shown by the results of several boreholes that have been executed by this means under every variety of circumstance as regards geological formation; and the following instances have been taken indiscriminately from various localities. The days mentioned are the ordinary working days of twelve hours, and Sundays and holidays have not been deducted in calculating the average depth per day for each borehole.

At Middlesbrough a borehole of 18 inches diameter throughout has been made to a depth of 1312 feet, the first 1160 feet through new red sandstone, interspersed with beds of clay, white sandstone, red marl, and gypsum; next came 40 feet of gypsum, hard white sandstone, and limestone; and the remaining 100 feet were through red sandstone, pure salt rock, occasional limestone, and then salt rock to the bottom. The gross number of days occupied in boring this well to the depth of 1312 feet was 540; and of this time 150 days were employed in pumping to test the quantity of water, together with other stoppages which retarded progress. The first 600 feet, at which depth the first stoppage to test water took place, were bored in 100 days from the commencement of the work, showing an average of 6 feet per day. The average progress for the extreme depth, including all stoppages from every cause, was 2 ft. 5 ins. per day; and the number of men employed never exceeded six, including the smith to sharpen the cutters.

At Norwich a borehole of 24 and 18 inches diameter has been made to a depth of 1184 feet. The first 700 feet were through

chalk interspersed with layers of large flints about 6 feet apart; then followed 400 feet of harder chalk, with beds of flint stones about 3 feet apart; and the remaining 84 feet to the bottom were through blue marl and gault clay. The presence of so many flints in this boring seriously impeded the progress, in consequence of the flints falling into the hole and jamming the tool. The first 900 feet were accomplished in 130 days, including all stoppages and delays, giving an average of 7 feet per day. For a period of one month during this time the rate of boring was 16 feet per day, or about 420 feet in 26 days of 12 hours. The average rate of boring through the whole depth, exclusive of stoppages, was 2 ft. 3 ins. per day; and including all delays and stoppages of every kind, 1 ft. 11 ins. per day. In executing this work difficulties arose from natural causes, which certainly put this system to the severest test: the hole was not tubed at all, so that neither rope nor boring-head had any protection in piercing through the conglomerate mass of chalk and flints, of which the strata are composed; and yet the rope sustained no serious injury from abrasion, as it must necessarily have done, had the hole not been true and perpendicular. Far more difficulty is experienced in boring a true hole in strata where it may constantly occur that one side is hard flint and the other soft chalk, than in the case of highly inclined beds of hard compact rock.

At Bradford a borehole of 24 and 18 inches diameter has been made from the bottom of a well 55 feet deep to the total depth of 350 feet. The first 50 feet were through soil, gravel, clay, and soft black shale; then 100 feet through hard black shale, hard stone, soft shale, coal bands, and hard stone shale; then 150 feet through hard white stone, hard dark rag, black shale, coal, stone shale, hard rag, blue shale, and thin beds of hard coal; and the remaining 50 feet to the bottom through white sandstone, millstone grit, quartz, &c. The gross time occupied was 190 days, including all delays and stoppages, giving an average progress of 1 ft. 10 ins. per day. The specimens exhibited show the nature of some of the strata. Cores, taken at every change in the strata, having a diameter of 5 inches and about 1 foot length, similar to

the specimens now exhibited, showed very perfectly the nature and quality of the rock, with its angle of inclination, &c. These cores are obtained by simply working the boring-head with all the inside cutters removed, leaving only the outside circle of cutters and the few cross chisels alternating with them round the circumference of the block; then by continued working a slightly conical core is formed, which may be made longer or shorter according to the length and inclination of the cutters; this core becomes finally jammed fast between the cutters and broken off at the root, and is then brought up to the surface by the boring-head. Beautiful specimens of coal have by this means been brought up, large enough to show the quality and dip of the seam.

At Halifax, Stockport, Pendleton near Manchester, Canterbury, Birkenhead, Walton near Wakefield, Loughborough, and Ramsaa in Norway, boreholes have been executed with this apparatus; and the particulars of these and several others are given in the accompanying Table. At the present time in the East Indies, West Indies, Norway, Russia, and various parts of Great Britain, boreholes are in process of being sunk by the writer's firm with this apparatus with complete success. One set of specimens that have come to hand, which are now exhibited, are from Assam in Central India, where a boring for petroleum has been executed. Three of these boring machines are now in India for the Public Works Department; and it is confidently expected that the blessing of a large supply of pure water to many a thirsty town and village will result from their operations, besides the discovery of fields of coal to feed the extending system of railways all over India.

A remarkable instance of a large town benefitting to an extraordinary extent by the operation of boring occurred at Hull. The whole town is now supplied with two million gallons per day of beautiful spring water from three contiguous boreholes of 18 and 15 inches diameter sunk by this apparatus to the depth of about 400 feet; the water in this case rises to the surface and overflows at the above rate, forming the largest free-flowing well on record.

*Particulars of Boreholes executed in different localities.*

| Locality. | Diameter of Borehole | | Depth of Borehole. | *Gross Time spent. | Rate of sinking per day. | | Description of Strata, and Remarks. |
|---|---|---|---|---|---|---|---|
| | Top. | Bottom. | | | | | |
| *Boreholes completed.* | Ins. | Ins, | Feet. | Days. | Ft. | In. | |
| Middlesbrough | 18 | 18 | 1312 | 540 | 2 | 5 | New red sandstone, clay, white sandstone, red marl, gypsum, limestone, red sandstone, and pure salt rock. First 600 feet bored in 100 days. Stoppages for pumping to test water 150 days. |
| Norwich | 24 | 18 | 1184 | 616 | 1 | 11 | Chalk and flints. First 900 feet bored in 130 days. |
| Walton, Wakefield | 9 | 9 | 770 | 517 | 1 | 6 | Coal measures; seam of coal 4 ft. 1 in. thick at 650 feet depth. Much time spent during boring of last 170 feet in clearing the hole of shale fallen in; stopped to put tubes down, and resumed boring inside the tubes. |
| Broughton, Manchester | 18 | 15 | 575 | 192 | 3 | 0 | Quicksand and gravel, red sandstone with seams of red marl, very hard sandstone, and clay. Borehole sunk from bottom of well 75 feet deep. |
| Canterbury No. 1 | 24 | 18 | 473 | 72 | 6 | 7 | Chalk and flints. |
| Do. No. 2 | 24 | 18 | 446 | 67 | 6 | 8 | Do. |
| Manchester | 24 | 15 | 466 | 95 | 4 | 11 | Red sandstone 110 feet, red and variegated marls 220 feet, coarse gravel and pebbles 43 feet, compact red and white sandstone 20 feet, red and purple marls 73 feet. Borehole sunk from bottom of well 70 feet deep. |
| Hathern, Loughborough | 9 | 9 | 455 | 142 | 3 | 2 | Gravel, red marl, red and white sandstone, bands of gypsum, and grey sandstone. |
| Salford, Manchester | 18 | 18 | 442 | ... | ... | | Gravel, red sandstone, red marl, white sandstone. Borehole sunk from bottom of well 20 feet deep. |
| Stockport | 18 | 18 | 424 | 91 | 4 | 8 | Red sandstone and red marl. |
| Weardale | 18 | 18 | 341 | 81 | 4 | 2 | Coal measures; shales, blue & white stone, clay, and coal, alternately. |
| Halifax | 15 | 15 | 332 | 100 | 3 | 4 | Chiefly hard flagstone. |
| Birkenhead | 18 | 18 | 322 | 61 | 5 | 3 | First 100 feet red and yellow sandstone; then white marl and sandstone alternately. Borehole sunk from bottom of well 186 feet deep, making total depth from surface 508 feet. |

* The total time in weeks has been taken in every case, without deducting Saturday afternoons and Sundays; and the days mentioned are the ordinary working days of 12 hours.

*Particulars of Boreholes (continued).*

| Locality. | Diameter of Borehole | | Depth of Borehole. | * Gross Time spent. | Rate of sinking per day. | Description of Strata, and Remarks. |
|---|---|---|---|---|---|---|
| | Top. | Bottom. | | | | |
| *Boreholes completed.* | Ins. | Ins. | Feet. | Days. | Ft. In. | |
| Collyhurst, Manchester | 9 | 9 | 309 | 97 | 3 2 | Marl, red sandstone, shale, hard white sandstone. |
| Bury, Lancashire | 9 | 9 | 300 | 142 | 2 1 | Coal measures; shale, white sandstone, and marl in layers. |
| Bradford, Yorkshire | 24 | 18 | 295 | 160 | 1 10 | Shales, sandstone, and coal bands alternately; millstone grit at bottom. Borehole sunk from bottom of well 55 feet deep. |
| Wirral, Birkenhead | 24 | 15 | 295 | 92 | 3 2 | Red and white sandstone, hard and fine. Borehole sunk from bottom of well 23 feet deep. |
| Tring | 18 | 18 | 260 | 43 | 6 0 | Chalk. |
| Pendleton, Manchester | 15 | 15 | 252 | 26 | 9 8 | New red sandstone. |
| Dundee, No. 1 | 18 | 18 | 247 | 200 | 1 3 | Whinstone. |
| Do. No. 2 | 18 | 18 | 234 | 155 | 1 6 | Do. |
| Do. No. 3 | 18 | 18 | 197 | 140 | 1 5 | Do. |
| Do. No. 4 | 18 | 18 | 60 | 19 | 3 2 | Do. |
| Birmingham | 18 | 18 | 172 | 49 | 3 6 | Hard and dark red sandstone, with pebbles; grey sandstone. |
| Caterham | 24 | 18 | 100 | 26 | 3 10 | Green sandstone, blue clay, grey and white sandstone, marl, chalk, and flints. |
| *Boreholes in progress.* | | | | | | |
| Levenshulme, Manchester | 18 | 18 | 432 | 80 | 5 4 | Red sandstone, red marl, clay, hard red sandstone. |
| Horse Fort, Spithead | 18 | 18 | 400 | 305 | 1 4 | Blue clay, sandy clay, and sandy shale. Borehole sunk from bottom of well 90 feet deep. |
| Ramsaa, Norway | 9 | 9 | 250 | 80 | 3 2 | Grey micaceous sandstone with iron pyrites and fossils; coarse grey sandstone. Seams of coal 12 inches thick at 205 feet depth, 6 inches at 219 feet, and 8 inches at 222 feet. |

* The total time in weeks has been taken in every case, without deducting Saturday afternoons and Sundays; and the days mentioned are the ordinary working days of 12 hours. In the case of the boreholes in progress, the time is taken up to the end of October 1869.

It will readily be conceived that in well-boring innumerable accidents and stoppages occur from causes which cannot be prevented, with however much vigilance and skill the operations may be conducted. Hard and soft strata intermingled, highly inclined rocks, running sands, and fissures and dislocations, are fruitful sources of annoyance and delay, and sometimes of complete failure; and it will therefore be interesting to notice a few of the ordinary difficulties arising out of these circumstances. In all the boreholes yet executed by this system, the various special instruments used under any circumstances of accident or complicated strata are fully shown in Plates 72 to 74.

The boring-head while at work may suddenly be jammed fast, either by breaking into a fissure, or in consequence of broken rock falling upon it from loose strata above. All the strain possible is then put upon the rope, either by the percussion cylinder or by the winding engine; and if the rope is an old one or rotten it breaks, leaving perhaps a long length in the hole. The claw grapnel, shown in Fig. 16, Plate 72, is then attached to the rope remaining on the winding drum, and is lowered until it rests upon the slack broken rope in the borehole. The grapnel is made with three claws A A centered in a cylindrical block B, which slides vertically within the casing C, the tail ends of the claws fitting into inclined slots D in the casing. During the lowering of the grapnel, the claws are kept open, in consequence of the trigger E being held up in the position shown in Fig. 16 by the long link F, which suspends the grapnel from the top rope. But as soon as the grapnel rests upon the broken rope below, the suspending link F continuing to descend allows the trigger E to fall out of it; and then in hauling up again, the grapnel is lifted only by the bow G of the internal block B, and the entire weight of the external casing C bears upon the inclined tail-ends of the claws A, causing them to close in tight upon the broken rope and lay hold of it securely. The claws are made either hooked at the extremity, as in Figs. 16 and 17, or serrated, as in Fig. 18. The grapnel is then hauled up sufficiently to pull the broken rope tight, and wrought-iron rods 1 inch square with hooks attached at the bottom are let down to catch the bow

of the boring-head, which is readily accomplished. Two powerful screw-jacks are applied to the rods at the surface, by means of the step-ladder shown in Figs. 23 and 24, Plate 72, in which the cross pin H is inserted at any pair of the holes, so as to suit the height of the screw-jacks.

If the boring-head does not yield quickly to these efforts, the attempt to recover it is abandoned, and it is got out of the way by being broken up into pieces. For this purpose the broken rope in the borehole has first to be removed, and it is therefore caught hold of with a sharp hook and pulled tight in the hole, while the cutting grapnel, shown in Figs. 19 and 20, Plate 72, is slipped over it and lowered by the rods to the bottom. This tool is made with a pair of sharp cutting jaws or knives I I opening upwards, which in lowering pass down freely over the rope; but when the rods are pulled up with considerable force, the jaws nipping the rope between them cut it through, and it is thus removed altogether from the borehole. The solid wrought-iron breaking-up bar, shown in Figs. 25 to 27, Plate 73, which weighs about a ton, is then lowered, and by means of the percussion cylinder it is made to pound away at the boring-head, until the latter is either driven out of the way into one side of the borehole, or broken up into such fragments as that partly by the shell-pump and partly by the grapnels the whole obstacle is removed. The boring is then proceeded with again, the same as before the accident.

The same mishap may occur with the shell-pump getting jammed fast in the borehole, as illustrated in Fig. 38, Plate 75; and the same means of removing the obstacle are then adopted. Experience has shown the danger of putting any greater strain upon the rope than the percussion cylinder can exert; and it is therefore usual to lower the grapnel rods at once, if the boring-head or pump gets fast, thus avoiding the risk of breaking the rope. Specimens are exhibited of portions of a boring-head and shell-pump which were broken up in the borehole as above described.

The breaking of a cutter in the boring-head is not an uncommon occurrence. If however the bucket grapnel, Figs. 32 to 34, or the small screw grapnel, Figs. 21 and 22, be employed for its recovery,

the hole is readily cleared without any important delay. The screw grapnel, Fig. 21, Plate 72, is applied by means of the iron grappling rods, so that by turning the rods the screw works itself round the cutter or other similar article in the borehole, and securely holds it while the rods are drawn up again to the surface. The bucket grapnel, shown in Figs. 32 to 34, Plate 74, is also employed for raising clay, as well as for the purpose of bringing up cores out of the borehole, where these are not raised by the boring-head itself in the manner already described. The action of this grapnel is nearly similar to that of the claw grapnel, Fig. 16; the three jaws A A, hinged to the bottom of the cylindrical casing C, and attached by connecting-rods to the internal block B sliding within the casing C, are kept open during the lowering of the tool, the trigger E being held up in the position shown in Fig. 32 by the long suspending link F. On reaching the bottom, the trigger is liberated by the further descent of the link F, which, in hauling up again, lifts only the bow G of the internal block B; so that the jaws A are made to close inwards upon the core, which is thus grasped firmly between them and brought up within the grapnel. A large number of specimens of cores are exhibited, of about 3 inches diameter, which have been brought up by this grapnel from different boreholes. Where there is clay or similar material at the bottom of the borehole, the weight of the heavy block B in the grapnel causes the sharp edges of the pointed jaws to penetrate to some depth into the material, a quantity of which is thus enclosed within them and brought up.

Another grapnel that is also used where a borehole passes through a bed of very stiff clay is shown in Figs. 35 to 37, Plate 74, and consists of a long cast-iron cylinder H fitted with a sheet-iron mouthpiece K at the bottom, in which are hinged three conical steel jaws J J opening upwards. The weight of the tool forces it down into the clay with the jaws open; and then on raising it, the jaws having a tendency to fall, cut into the clay and enclose a quantity of it inside the mouthpiece, which on being brought up to the surface is detached from the cylinder H and cleaned out. A second mouthpiece is put on and sent down for working in the

borehole while the first is being emptied, the attachment of the mouthpiece to the cylinder being made by a common bayonet-joint L, so as to admit of readily connecting and disconnecting it.

A running sand in soft clay is however the most serious difficulty met with in well-boring. Under such circumstances the borehole has to be tubed from top to bottom, which greatly increases the expense of the undertaking, not only by the cost of the tubes but also by the time and labour expended in inserting them. When a permanent water supply is the main object of the boring, the additional expense of tubing the borehole is not of much consequence, as the tubed hole is more durable, and the surface water is thereby excluded; but in exploring for mineral it is a serious matter, as the final result of the borehole is then by no means certain. The mode of inserting tubes has become a question of great importance in connection with this system of boring, and much time and thought having been spent in perfecting the method now adopted, its value has been proved by the repeated success with which it has been carried out.

The tubes are of cast-iron, varying in thickness from $\frac{5}{8}$ to 1 inch according to their diameter, and are all 9 feet in length, as shown in Fig. 39, Plate 75. The successive lengths are connected together by means of wrought-iron covering hoops 9 inches long, made of the same outside diameter as the tube, so as to be flush with it. These hoops are from $\frac{1}{4}$ to $\frac{3}{8}$ inch thick, and the ends of each tube are reduced in diameter by turning down for $4\frac{1}{2}$ inches from the end, to fit inside the hoops, as shown in Fig. 39. A hoop is shrunk fast on one end of each tube, leaving $4\frac{1}{2}$ inches of socket projecting to receive the end of the next tube to be connected. Four or six rows of screws with counter-sunk heads, placed at equal distances round the hoop, are screwed through into the tubes to couple the two lengths securely together. Thus a flush joint is obtained both inside and outside the tubes. The lowest tube is provided at the bottom with a steel shoe, having a sharp edge for penetrating the ground more readily, as shown to a larger scale in the section, Fig. 40.

In small borings, from 6 to 12 inches diameter, the tubes are inserted into the borehole by means of screw-jacks, by the simple and inexpensive method shown in Figs. 41 and 42, Plate 76. The boring machine foundation A A, which is of timber, is weighted at B B by stones, pig-iron, or any available material; and two screw-jacks C C, each of about 10 tons power, are secured with the screws downwards, underneath the beams D D crossing the shallow well E, which is always excavated at the top of the borehole. A tube F having been lowered into the mouth of the borehole by the winding engine, a pair of deep clamps G are screwed tightly round it, and the screw-jacks acting upon these clamps force the tube down into the ground. The boring is then resumed, and as it proceeds the jacks are occasionally worked, so as to force the tube if possible even ahead of the boring tool. The clamps are then slackened and shifted up the tubes, to suit the length of the screws of the jacks; two men work the jacks, and couple the lengths of tubes as they are successively added. The actual boring is carried on simultaneously within the tubes, and is not in the least impeded by their insertion, which simply involves the labour of an additional man or two.

A more perfect and powerful tube-forcing apparatus is adopted where tubes of from 18 to 24 inches diameter have to be inserted to a great depth, an illustration of which is afforded by an extensive piece of work now in progress at the Horse Fort, standing in the channel at Gosport. This fort is simply a huge round tower, as shown in Fig. 47, Plate 78; and to supply the garrison with fresh water, a borehole is being sunk into the chalk. A cast-iron well A, consisting of cylinders 6 feet diameter and 5 feet long, has been sunk 90 feet into the bed of the channel in the centre of the fort, and from the bottom of this well an 18 inch borehole B is now in progress. The present depth is 400 feet, and the borehole is tubed the whole distance with cast-iron tubes 1 inch thick, coupled as before described.

The method of inserting these tubes is shown in Figs. 43 to 46, Plate 77, and is as follows. Two wrought-iron columns C C, 6 inches diameter, are firmly secured in the position shown, by

castings bolted to the flanges of the cylinders A A forming the well, so that the two columns are perfectly rigid and parallel to each other. A casting D, carrying on its underside two 5 inch hydraulic rams I I of 4 feet length, is formed so as to slide freely between the columns, which act as guides; the hole in the centre of this casting is large enough to pass a bore tube freely through it, and by means of cotters passed through the slots in the columns the casting is securely fixed at any height. A second casting E, exactly the same shape as the top one, is placed upon the top of the tubes B B to be forced down, a loose wrought-iron hoop being first put upon the shoulder at the top of the tube, large enough to prevent the casting E from sliding down the outside of the tubes; this casting or crosshead rests unsecured on the top of the tube and is free to move with it. The hydraulic cylinders I, with their rams pushed home, are lowered upon the crosshead E, and the top casting D to which they are attached is then secured firmly to the columns C by cottering through the slots. A small pipe F, having a long telescope joint, connects the hydraulic cylinders I with the pumps at the surface which supply the hydraulic pressure. By this arrangement a force of 3 tons per square inch, or about 120 tons total upon the two rams, has frequently been exerted to force down the tubes at the Horse Fort. After the rams have made their full stroke of about 3 ft. 6 ins., the pressure is let off, and the hydraulic cylinders I with the top casting D slide down the rams resting on the crosshead E, until the rams are again pushed home. The top casting D is then fixed in its new position upon the columns C, by cottering fast as before, and the hydraulic pressure is again applied; and this is repeated until the length of two tubes, making 18 feet, has been forced down. The whole hydraulic apparatus is then drawn up again to the top, another 18 feet of tubing added, and the operation of forcing down resumed. The tubes are steadied by guides at G and H, Fig. 43, as shown also in the plans, Figs. 45 and 46.

The boring operations are carried on uninterruptedly during the process of tubing, excepting only for a few minutes when fresh tubes are being added. It will be seen that the cast-iron well is in this case the ultimate abutment against which the pressure is exerted in

forcing the tubes down, instead of the weight of the boring machine with stones and pig-iron added, as in the case where the screw-jacks are used; the hydraulic method was designed specially for the work at Gosport, and has acted most perfectly. Both the cast-iron well and the borehole are entirely shut off from all percolation of sea water, by first filling up the well 30 feet with clay round the tubes, and making the tubes themselves water-tight at the joints at the time of putting them together. This boring has already penetrated 400 feet into shingle, sand, and blue clay, and is now entering the chalk; and pure fresh water fills the hole. Another 100 feet added to the depth will undoubtedly give the desired results as to quantity, whereby the success of the whole undertaking will be completed.

In the event of any accident occurring to the tubes while they are being forced down the borehole, such as requires them to be drawn up again out of the hole, the prong grapnel shown in Figs. 28 and 29, Plate 73, is employed for the purpose, having three expanding hooked prongs, which slide down readily inside the tube, and spring open on reaching the bottom; the hooks then project underneath the edge of the tube, which is thus raised on hauling up the grapnel. In case the tubes get disjointed and become crooked during the process of tubing, the long straightening plug shown in Figs. 30 and 31 is lowered down inside them, consisting of a stout piece of timber faced with wrought-iron strips; above this is a heavy cast-iron block, the weight of which forces the plug past the part where the tubes have got displaced, and thereby straightens them again.

Although there are few localities where the geological formation is not favourable to the yield of pure water if a boring be carried deep enough, yet it rarely happens that free-flowing wells such as those in Paris and Hull are the result. Generally after the water-bearing strata have been pierced, the level to which the water will rise is at some depth below the surface of the ground; and only by the aid of pumps can the desired supply be brought to the surface. Various pumping arrangements have therefore been adopted to suit the different conditions that are met with.

It is always desirable to sink a cast-iron well, such as that at the Horse Fort, as nearly as possible down to the level at which the water stands in the borehole. The sinking of such a well is rendered an easy and rapid operation, with the aid of the boring machine in winding out the material from the bottom, and keeping the sinkers dry by the use of the dip bucket, shown in Figs. 48 to 50, Plate 79, which will lift from 50 to 100 gallons of water per minute, for taking off the surface drainage. A well having thus been made down to the level of the water in the borehole, the permanent pumps are then applied to the borehole as follows, the size of the pumps varying according to the diameter of the borehole. Taking the case of a 15 inch borehole, a pump barrel consisting of a plain cast-iron cylinder, say 12 inches diameter and 12 feet long, as shown in section in Fig. 57, Plate 82, is attached at the bottom of cast-iron or copper pipes, which are $\frac{1}{4}$ inch larger in diameter than the pump barrel, and are coupled together in lengths by flanges, as shown in Fig. 54, Plate 80. By adding the requisite number of lengths of pipe at the top, the pump barrel is lowered to any desired depth down the borehole: the nearer to the depth of the water-bearing strata the better. The topmost length of pipe has a broad flange at its upper end, which rests upon a preparation made to receive it on the cast-iron bottom of the well, as shown at C in Fig. 51, Plate 80.

A pump bucket D, Figs. 57 and 58, Plate 82, with a water passage through it and a clack on the top side, is then lowered into the barrel, being suspended by a solid wrought-iron pump-rod E, which is made up of lengths of 30 feet coupled together by right-and-left-hand screwed couplings, as shown in Fig. 53. A second bucket F of similar form is also lowered into the pump barrel, above the first bucket, and is suspended by hollow rods G coupled together in the manner just described, as shown in Fig. 53; the inside diameter of the hollow rods G being such that the couplings of the solid rods E may pass freely through. The pump rods are carried up the well A to the surface, where the hollow rod of the top bucket is attached to the horizontal arm of a bell-crank lever H, Fig. 51, Plate 80; and the solid rod of the bottom bucket, passing up through the hollow rod of the top bucket, is suspended from the

horizontal arm of a second reversed bell-crank lever K, facing the first lever H. As the extremities of the horizontal arms of the levers meet over the centre of the well, one of them is made with a forked end, as shown in plan in Fig. 52, to admit of the other passing it. The vertical arms of the two levers are coupled by a connecting rod L, and a reciprocating motion is given to them by means of an oscillating steam cylinder M, the piston-rod of which is attached direct to the extremity of one of the vertical arms; a crank and flywheel N are also connected to the levers, for controlling the motion at the ends of the stroke. With the proportion shown in the drawing of 3 to 4 between the horizontal and vertical arms of the bell-crank levers, the stroke of 5 ft. 4 ins. of the steam piston gives 4 feet stroke of the pump. The reciprocating motion of the reversed bell-crank levers causes the two buckets to move always in opposite directions, so that they meet and separate at each stroke of the engine. A continuous flow of water is the result, for when the top bucket is descending, the bottom bucket is rising and delivering its water through the top bucket; and when the top bucket rises, it lifts the water above it while the bottom bucket is descending, and water rises through the descending bottom bucket to fill the space left between the two buckets. In this way the effect of a double-acting pump is produced.

Although a continuous delivery of water is thus obtained of equal amount in each stroke, it is found in practice that a heavy shock is occasioned at each end of the stroke, in consequence of both the buckets starting and stopping simultaneously, causing the whole column of water to be stopped and put into motion again at each stroke. As an air-vessel for keeping up the motion of the water is inapplicable in such a situation, a modified arrangement of the two bell-crank levers has been adopted, which completely answers the purpose, causing each bucket at the commencement of its upstroke to take the lift off the other, before the upstroke of the latter is completed. By this means all shock is avoided, as the first bucket gently and gradually relieves the second, before the return stroke of the second commences.

In this improved pumping motion, which is shown in Figs. 55 and 56, Plate 81, the two bell-crank levers H and K, working the pump buckets, are centered one above the other, the upper one being inverted; and the vertical arms are slotted, and are both actuated by the same crank-pin working in the slots, the revolution of the crank thus giving an oscillating movement to the two levers through the extent of the arcs shown by the dotted lines in Fig. 55. The solid pump-rod E suspending the bottom bucket D is attached to the upper bell-crank lever K, and the hollow rod G of the top bucket is suspended from the lower lever H; the crank shaft J working the levers is made to revolve in the direction shown by the arrow in Fig. 55, by means of gearing driven by the horizontal steam engine P.

The result of this arrangement is, that in the revolution of the crank the dead point of one of the levers is passed before that of the other is reached; so that the bucket which first comes to rest at the end of its stroke is started into motion again before the second bucket comes to rest. Thus in the lifting stroke of the bottom bucket worked by the upper lever K, the bucket in ascending has only reached the position shown at D in Fig. 57, Plate 82, at the moment when the top bucket worked by the lower lever H arrives at the bottom extremity of its stroke, as shown at F in Fig. 57; and the bottom bucket D, which is still rising, continues to lift until it reaches its highest position indicated by the dotted lines at Q, by which time the top bucket has got well into motion in its upstroke, and is in its turn lifting the water. Similarly when the lifting stroke of the top bucket is drawing to a close, the bottom bucket arrives at the lowest extremity R R of its stroke when the top bucket in ascending has only reached the position S S, and has still to rise further to its highest position T T before it ceases to lift; by which time the bottom bucket has got well into motion again in its lifting stroke. On each turn of the stroke therefore, both buckets are simultaneously lifting during the time occupied by the passage of the crank through the interval between the dead points of the two bell-crank levers; so that by the time one of the buckets ceases lifting, the other is already doing its work. A steady continuous

flow of water is thus obtained, without any pause occurring in it, and no shock or vibration is produced at either end of the stroke; consequently no air vessel is required either to maintain the upward flow of the rising column of water, or to ease the closing of the bucket clacks at the ends of the stroke; and the foot-valve U, Fig. 51, which in the previous arrangement of the bell-crank levers was provided at the bottom of the pump barrel for mitigating the concussion in stopping the rising column of water, may be dispensed with by this improved motion shown in Fig. 55, as the rising column of water is never allowed to come to rest. The speed of lifting is slow at each end of the stroke, while the two levers are successively passing the dead points of the crank; and the speed gradually increases when the lifting bucket has got well hold of the water, and then decreases again towards the end of the stroke.

Several of these pumps and engines are now at work with lifts of from 150 to 200 feet, and have been in operation for five or six years, without the makers being once called upon to repair them. The buckets may readily be drawn up and lowered again into the pump barrel from the surface; and where there is a well at the top of the borehole, as in Figs. 51 and 55, advantage is taken of it to place guides for the outside hollow pump-rod. The same plan of pumping has also been applied to deep wells, such as colliery shafts, where the quantity of water is so great as not to admit of its being emptied by temporary pumps for the purpose of fixing the ordinary pumps with air-vessels, &c. The chief purpose however of this plan is to reach the deep springs of water opened up by boreholes, where the level of the water is a great distance below the surface. The great expense and difficulty of following down the boring with a large well, in which to place the pumps, are thus avoided; while every advantage is secured which is necessary to a permanent water supply.

In conclusion it may be mentioned that altogether more than 20,000 feet of boring from 6 inches to 24 inches diameter have been successfully accomplished by the boring apparatus now described; and every day proves that there are no difficulties too great to be overcome in this manner by the exercise of perseverance and energy;

and it is hoped sufficient evidence has been given that in this branch of mechanical engineering England may claim to share the honours with her continental neighbours.

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Mr. Mather exhibited a specimen of the boring-head, showing the action of the ratchet-teeth in rotating the head between each blow; and also a specimen of the shell-pump for bringing up the material from the bottom of the borehole, together with a working model of the pump, showing its action. He showed also a quantity of iron fragments that had been brought up by the shell-pump from boreholes in which one or other of the implements had got jammed too fast to be brought up by the grapnel, and had therefore been broken up by the heavy breaking bar being let fall upon them in the borehole, so as to break them into pieces small enough to be brought up by the pump. A large collection of cores from various boreholes was also exhibited, showing the nature of the strata passed through.

He explained that the grapnel, employed for bringing up an implement left at the bottom of the borehole by breakage of the rope or other accident, was constructed with three long claws, which were centered in a cast-iron block sliding within a cylindrical casing, and the tail end of each claw passed through a slot in the cylinder. In lowering the grapnel down the hole, the claws were kept open, in consequence of the cylindrical casing being then supported in its highest position by a small trigger held up by the suspending link from the winding rope, as shown in Fig. 16; but as soon as the claws of the grapnel rested upon any solid object, the long suspending link continuing to descend allowed the supporting trigger to disengage itself; and then on winding the rope up again the weight of the cylindrical casing bearing on the tail ends of the claws caused them to close tight upon the implement in the borehole with a nipping action, and lay hold of it by the lifting bow or by any projection that

the claws happened to engage with. This simple construction formed a powerful grapnel, which had been found very effective for recovering any of the large implements from the bottom of the boreholes. If the object laid hold of by the grapnel would not yield and come up with it, the heavy breaking bar had to be resorted to, for breaking up the implement into pieces small enough to be raised by the shell-pump; in such a case, as the grapnel could not be disengaged when once caught, it would have also to be left at the bottom of the borehole and broken up with the rest, the rope being previously cut away from it at the bottom by means of the cutting grapnel. Such an accident as a cutter dropping out of the boring-head was of very rare occurrence, and could only arise from carelessness in fixing the cutter in the boring-head; and for recovering a lost cutter or any other small article dropped in the borehole, the screw grapnel shown in Fig. 21 was employed, attached to the bottom of iron rods 1 inch square, by which it was lowered down the borehole; by turning the rods the screw grapnel worked itself round the cutter or other similar article, and held it securely while the rods were drawn up to the surface: this simple plan was generally found successful in practice.

Of the boreholes enumerated in the Table accompanying the paper, some were tubed throughout their entire depth, others only partially, and others not at all, according to the nature of the strata passed through. The conditions under which an ample supply of water might be calculated upon from a borehole were when the boring could be carried down to the porous strata underlying a bed of clay; these strata were found to contain vast quantities of water, and as soon as they were pierced by the borehole the water rose in abundance, either to the surface of the ground, constituting an artesian or free-flowing well, or to a distance from the surface, varying according to the circumstances of the geological formation of the neighbourhood. The excellent and abundant supply of pure spring water now enjoyed by the town of Hull, in place of the previous river water contaminated with sewage, was obtained entirely from borings sunk by the process described in the paper; and this great boon to the inhabitants was solely due to the enterprise and public spirit of Mr. Warden of that

town, who had put down three successive boreholes entirely at his own expense, in the confident belief that there was an ample supply of fresh water to be obtained from the underlying strata; the result had fully verified this anticipation, the water rising to the surface and overflowing in great abundance. It was greatly to be regretted however that the originator of this valuable water supply had not yet received any recognition of the important public service he had thus rendered, nor even been reimbursed the amount he had expended on the work.

Mr. H. Beckett considered the plan of boring described in the paper was a most admirable one, and for the purpose of trial boreholes in searching for minerals it would be particularly advantageous, the small boreholes previously adopted having been very unsatisfactory, especially in faulty ground, as the broken and mixed materials that were brought up did not give sufficiently clear indications of the nature of the strata passed through. But with the solid cores, such as those exhibited, that were obtained by the plan now described, the boring had more the character of a regular sinking, and it was clear that the indications which it afforded of the strata passed through would be thoroughly reliable, even in difficult ground. In the North Wales coalfield an instance had occurred of seven different boreholes of small diameter being put down upon an estate, with the result only of leading to the conclusion that the coal did not exist in sufficient thickness to render its working practicable; but when, notwithstanding this discouragement, a sinking was afterwards prosecuted, the main bed of coal of 12 feet thickness was met with at only 70 yards depth. In this case a single boring on the plan now described would at the outset have proved the existence and thickness of the coal with as much certainty as the sinking itself. He enquired whether any of the boreholes executed had been through coal measures, and whether cores of coal had been brought up as large as the specimens of cores exhibited from other strata.

Mr. Mather said that some of the boreholes he had executed had passed through coal, and the cores obtained of the coal had been as large as any of the specimens exhibited of cores from other strata,

showing distinctly by the lines of partings the direction of dip of the strata.

Mr. E. A. Cowper thought the boring apparatus now described was most valuable and was well calculated to give a satisfactory knowledge of the strata passed through. As the winding rope employed was a flat one, it had the advantage of bringing up the cores without any twist, and would thus show correctly the direction of the dip of the strata; the lines of stratification were clearly seen in some of the specimens of cores exhibited, and where partings occurred in the strata, as in the case of coal seams, he supposed the cores would be most likely to break off at the partings, so that the actual inclination of the seam would be shown by the bottom face of the cores, as well as by the marks of stratification on their sides. It was very satisfactory to find that as many as 24 blows per minute could be given with the boring tool by this apparatus; and from the mode of working it was evident that the tool fell so freely as to strike the blow with its full weight at the bottom of the borehole, in consequence of the rope being at liberty to fall perpendicularly with the tool, without being retarded by running off a drum in the fall. With such a number of blows per minute given by the free-falling tool, there could be no doubt the boring must be very effectively accomplished. In connection with the mode of recovering any implement by means of the grappling tools that had been described, he might mention that, in a case of breakage of a timber pump-rod 6 inches square in a well pump, he had employed simply a ring of square section, to which the lifting chain was attached on one side, the ring being first suspended in a horizontal position by cords when lowering it down the hole; and it was guided to drop over the broken head of the pump-rod, by a guide-rod provided at the bottom with expanding feelers opening just enough to enclose the head of the pump-rod; as soon as the ring had slipped over the head of the rod, the cords suspending it horizontally were let go and the lifting chain was hauled up, thereby canting the ring upon the rod, which was thus nipped tight with sufficient hold for raising it successfully by the lifting chain. He enquired whether it was not the case, in working the boring tools by the rope system,

that the most dangerous and troublesome accident was when the rope broke near the top of the borehole, because the hole would then become choked with a quantity of rope jammed in it, which he supposed could not easily be reduced to small pieces even by the very heavy breaking bar that was employed to break up the boring-head when the grapnel was unsuccessful.

Mr. MATHER said that, in the event of the rope breaking at a considerable height above the bottom, the rope left in the borehole was got hold of by a hook grapnel and drawn up tight, and was then cut off as near the bottom as possible by means of the cutting grapnel, shown in Fig. 19, the jaws of which nipped the rope tight at the bottom and were made with sharp edges to cut it through; this cutting grapnel was slipped down over the rope, passing over the upper hook grapnel which had hold of the rope at the top. The broken rope being thus cut off and drawn up, the implement at the bottom of the borehole could then either be recovered by the claw grapnel, or broken to pieces by the heavy breaking bar.

The CHAIRMAN enquired what was found to be the durability of the ropes used for working the boring tools.

Mr. MATHER replied that with proper usage the ropes lasted for several years, if care was taken to tar them afresh before putting away when out of use, and not to leave them damp upon the winding drum. He exhibited a number of specimens of ropes that had been employed for different lengths of time and in different geological formations, one of them having lasted for four successive boreholes, each of which was several hundred feet deep. The two outside strands were of course the first to give way, in consequence of rubbing occasionally against the sides of the borehole in working.

The CHAIRMAN enquired whether the rotating movement of the boring-head between the successive blows had ever been found to fail in working; and whether any of the cores that had been brought up from the boreholes had afforded evidence of the rotation of the boring tool.

Mr. MATHER said that one of the cores now exhibited had brought up a flat disc attached to its base, of nearly the full diameter of the hole, and the upper annular face of the disc was distinctly marked all

round by a succession of radial lines with considerable regularity of position, corresponding to the successive blows of the tool; such specimens were frequently met with, and they gave most satisfactory evidence of the efficient working of the arrangement for rotating the tool, and no instance whatever had occurred of its failing to act. That method of effecting the rotation was of course dependent upon the use of a flat rope, in order that the rope after being twisted by the ratchet-teeth on the lifting shackle should readily untwist itself again during the lifting of the boring tool. When tightened by the weight of the heavy tool suspended at the bottom, the rope was indeed more like a rigid bar, very sensitive to any twisting motion; and by taking hold of the rope with the hand at the top of the borehole, it was easy to tell by the feeling what was going on at the bottom of the hole.

Mr. W. S. Longridge enquired whether the ropes used had in all cases been hemp ropes, or whether wire ropes had been tried in any instance.

Mr. Mather said he had not tried wire ropes, having found the hemp ropes strong and durable enough in all cases; and he had therefore not thought it necessary to go to the expense of a wire rope.

The Chairman enquired whether any comparison could be given of the cost of boring by the rope system and by rods, for different depths of boreholes.

Mr. Mather replied that the rope system was not recommended for borings less than 200 feet deep on account of the expense of the machinery required, and down to that depth it was found the boring could be done more cheaply by the use of rods; but as the depth became greater, the cost of the rod system increased at a rapid rate, in consequence of the difficulties attending the management of a great length of heavy rods, and the serious loss of time in lifting and lowering the rods in regular working, besides the very frequent delays from accidents. Moreover the rod system as usually carried out was only suitable for executing boreholes of small diameter; and the large borings at present being sunk in Paris by means of rods required all the apparatus employed to be constructed upon a scale of excessive magnitude. In these cases he had observed that the number of men required to be constantly employed was three times

as great as in the borings executed by the rope system, the latter requiring only one man to attend to the winding engine and percussion cylinder, and two labourers at the mouth of the borehole for changing the tools and clearing away the stuff brought up, whatever the size of the borehole that was being executed. The smith's work in sharpening the cutters was of course additional labour attending either plan of boring alike.

The CHAIRMAN enquired what was the greatest depth to which the double-acting pumping arrangement described in the paper had been carried in actual working; it appeared to him a very ingenious plan of pumping from a great depth without concussion of the water at the ends of the stroke.

Mr. MATHER said the greatest depth at which the double-acting pump had been worked in any of the boreholes was 200 feet, and it was very rare for the water in a boring not to rise at least to that distance from the surface of the ground. At the present time one of the pumps was working in a borehole at the depth of 200 feet, and the water was now rising to a higher level in the boring.

Mr. T. S. WHITTEM asked what was the greatest diameter of borehole that had been executed by the rope system now described.

Mr. MATHER replied that the largest diameter that had been carried down to the bottom of boreholes sunk by this plan was 18 inches; and the deepest borehole was the one at Middlesbrough of 1312 feet depth and 18 inches diameter, which was continued through the whole depth at that diameter.

Mr. H. BECKETT asked to what depth it was considered this mode of boring could be carried in practice.

Mr. MATHER said he had offered to put down a borehole in Surrey of 3 feet diameter to a depth of 4000 feet, to test the existence of the deep bed of coal which geologists believed would be found there; and he was satisfied that with the flat rope system there would not be any difficulty in carrying the boring to that depth.

Mr. SAMPSON LLOYD considered the plan of boring described in the paper would be applicable with great advantage in the South Staffordshire and East Worcestershire coalfield, for proving the existence and depth of a continuation of the Thick coal of that district.

The few experimental borings that had hitherto been made with this object had not turned out satisfactorily, as there had not only been a difficulty in the application of previous boring machinery, but there had always been great uncertainty as to what was being bored through, in regard both to the quality and thickness of the strata; and it had been impossible to arrive at any reliable conclusion upon the very question which the borings were intended to decide. With the boring tool now described however, capable of bringing up cores like those exhibited, he considered a borehole would be quite equal to a sinking, in proving definitely the nature of the strata bored through. Such borings, put down in different parts of that district, he had little doubt would prove the existence of a much greater extent of coal still to be developed than had yet been worked; and he trusted it would not be long before the work of exploring was prosecuted with energy, as he thought the time was come when it would be found highly advantageous for this to be done.

The Chairman mentioned that some years ago he had had a borehole of 18 inches diameter put down to a depth of 180 feet at Whitmore Station on the London and North Western Railway, by the plan of boring described in the paper; and the work had been done very promptly and in the most satisfactory manner in all respects, no difficulties whatever having occurred to interfere with the success of the operation. Since that time several points had been developed which he had not previously been acquainted with in this mode of boring; and he was particularly struck with the very beautiful arrangement of the double-acting pump, for pumping from a borehole without any shock upon the pump at the ends of the stroke, whatever might be the depth from which the water was being raised. In this as well as in several other respects he thought the plan of boring now described gave evidence of much practical mechanical ability having been brought to bear in working it out so successfully.

He moved a vote of thanks to Mr. Mather, which was passed, for his paper and for the extensive and interesting collection of specimens that he had exhibited in illustration of the subject.

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The following paper was then read:—

# DESCRIPTION OF AN IMPROVED MACHINE FOR SHAPING NUTS, &c.

By Mr. WILLIAM F. BATHO, of Birmingham.

The old process of filing up the hexagonal heads and nuts of bolts was a tedious and costly operation before the introduction of self-acting tools for the purpose; but since these have come more generally into use, many different kinds of machines have been designed for the special purpose of Shaping Nuts and the heads of bolts. None of these however have hitherto been contrived to operate on more than two sides of the same nut at once; and many of the machines have been constructed with circular or rose cutters, which are very expensive to make and maintain.

The machine now to be described is arranged for the purpose of shaping the external faces of nuts and various other articles by means of a number of cutting tools acting simultaneously on all the faces of the work. It is shown in Figs. 1 to 5, Plates 83 to 85, and consists of six horizontal revolving cutters A A, arranged radially at the same level in the frame B of the machine, and all driven by a single bevil wheel C gearing into the six bevil pinions D D that carry the cutter spindles. The cutters are so fixed in their spindles that when the cutting edges of one tool are vertical those of the adjoining ones on either side are horizontal, each cutter being placed a quarter of a revolution in advance of the next, as shown in the plan, Fig. 2. They consequently miss one another in revolving, although each intersects the path of the adjoining ones; and they can thus operate on work the faces of which are narrower than the breadth of the cutters. By this means the contiguous faces of hexagonal nuts are all shaped simultaneously by the revolving cutters.

The shape of the cutters is similar to that of the roughing-out drill previously adopted by the writer when designing the slot-drilling machine. This kind of cutter, which is shown to a larger scale in Figs. 6 to 8, Plate 85, has been found to last very long in work and to be very cheap to make; and it occurred to the writer that it might be used with advantage in the shaping of hexagonal nuts and other similar work having a uniform external polygonal form. The principle of this cutter consists in shaping the edge so that the cutting portions are limited to the two sides of the tool, acting like two independent cutters fixed in a revolving cross arm, as in an ordinary fly-cutter, so that the cutting action is similar to that of a roughing-out tool in a lathe or planing machine. With this shape the cutters are found very efficient and perfect in their work, and the wear upon them is so small that each lasts a long time before it is ground down so low as to require renewal. Different sizes of cutters are used, according to the size of the work to be shaped; but the number of revolutions per minute are regulated so as to give a uniform speed to the cutting edge of about 30 feet per minute, the vertical feed or traverse of the work being about 1 inch per minute.

The work to be shaped is held between centres in the top and bottom traversing frames E and F, Fig. 1; and these two frames are secured together by three vertical shafts G G, which slide up and down in bushes in the main frame B of the machine. The lower part F of the traversing frame is made in the form of a dish, with a central boss H projecting upwards, to carry a steel centre or a socket or chuck, according to the nature of the work to be shaped; and on its underside is fixed a long hollow screw K, by which the vertical feed motion is given. The bottom of the dish F has radial openings cast in it, through which the cuttings produced by the tools pass down the hollow screw K, thus obviating any risk of damage to the working parts of the machine from accumulation of the cuttings. In the engravings the machine is represented working upon the common hexagonal nuts N N, which are threaded upon a close-fitting vertical mandril carried centrally in the traversing frame, the lower end of the mandril being made square to fit into a

square socket in the boss H, Fig. 1. The vertical feed-motion of the frame F traverses the nuts upwards or downwards in the middle of the revolving cutters A; and the shaping of the six faces of the whole row of nuts on the mandril is completed in a single traverse of the machine.

The feed motion is obtained from the main driving shaft L through the pair of small cone pulleys M and P for varying the rate of feed. A bevil wheel on the shaft of the lower cone pulley P drives the two reversed bevil wheels J J, Fig. 3, running loose upon the shaft of the worm Q; this engages with the worm-wheel S, the boss of which is screwed and forms the nut upon the long traversing screw K, Fig. 1. Either of the bevil wheels J is thrown into gear with the worm shaft Q by means of the clutch I sliding upon a feather on the shaft, Fig. 3; and an upward or downward traverse is thus given to the mandril carrying the nuts N. In Fig. 5, Plate 85, is shown a separate view of the self-acting tappet arrangement, for stopping the feed motion when the cutters have traversed over the distance required. The two tappets T T upon the vertical rod R being adjusted at the proper heights for the length of traverse required, their projecting arms are caught by the edge of the bottom dish F at either extremity of its vertical traverse; and by means of the inclined slot in the tappet-rod R the clutch I is thus drawn out of gear with the bevil wheel J with which it was engaged. The feed motion is thereby stopped, and the clutch remains out of gear until it is put into gear again by hand, which is done by shifting the tappet-rod R forwards in the direction it was going; this throws the clutch into gear with the opposite bevil wheel, and so reverses the feed motion or vertical traverse of the frame F.

The adjustment of the cutters A to the required distance from the centre of the machine, to suit different diameters of work, is effected by means of the handwheels W, Fig. 4, Plate 85, their bosses being screwed to fit upon the long hollow bush in which each cutter spindle A revolves; the bush itself is prevented from turning by a key working in a groove on the underside of the bush. The inner handwheel is held in the frame of the machine between the

bearings which carry the cutter spindle, and the outer handwheel serves as a lock-nut to prevent the spindle from working back in consequence of the jar of the cutters. Three steel washers are inserted between the screwed bush and the shoulder on the cutter spindle, for taking the end thrust of the cutter spindle in working, the two outside washers being secured by screws to the end of the bush and the shoulder of the spindle respectively.

In contriving machinery for saving labour in the manufacture of finished bolts and nuts, there has not been in the writer's opinion so much ingenuity displayed as in other branches of manufacture of similar articles, where the demand is very great; and if the same ingenuity and enterprise had been brought to bear upon this object, there appears no reason why highly finished bolts should not be manufactured so well by self-acting machinery, and sold so cheaply, that it would not pay any engineer to make his own bolts, any more than it does now to make his own wood screws.

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Mr. Batho exhibited a small-size specimen of the machine, together with a number of finished nuts of various sizes and other work shaped by the machine, and also specimens of different cutters employed. He explained that the shaping of squares, of which specimens were exhibited, was either done by a similar machine made with four cutters, for shaping the four sides simultaneously; or it could be done in the hexagonal shaping machine, by using only two out of the six cutters, for shaping two opposite sides of the square, and then turning the work one quarter round for shaping the two other sides. By giving the work a rotating movement during its traverse in front of the cutters, it could be shaped as a spiral, and a variety of different forms could be produced.

The Chairman enquired what was the rate of production by the machine in regular working, and whether the work had to be gone over twice for finishing it, and also what was found to be the durability of the cutters.

Mr. Batho replied that the vertical traverse or feed motion was about one inch per minute, and the work was finished by the machine at that rate, as it was completed entirely in a single course, and did not require going over a second time or touching by hand after leaving the machine: the whole of the specimens exhibited had been finished at one cut. The speed of revolution of the cutters was regulated according to their size, so as to give in all cases the same speed of about 30 feet per minute at the extremities of the cutting edges.

Mr. F. F. Smith said it had been found at Messrs. Nettlefold's Screw Works, where several of these shaping machines were in regular use, that the cutters would shape about one gross of nuts, of 1 inch thickness, before requiring to be sharpened; and a set of the cutters would complete from 50 to 60 gross of nuts of that size, before they were worn out. He exhibited a set of the cutters which had done that amount of work, and had been shortened about 1 inch from their original length by grinding. The form of cutter employed was found very efficient for the purpose, and it had the advantage of being very rigid and free from any liability to spring or get broken in working, all the cutters having stood the work until ground down too short to be of any further use.

Mr. Mather enquired whether the nuts to be shaped were put into the machine in their rough forged state, or whether they were faced and tapped before shaping.

Mr. F. F. Smith replied that the nuts were drilled and faced before shaping, and were tapped either before or after, according to the supply of work that there might be for the tapping machines. There was no objection to the shaping being the final operation performed on the nuts, because the machine had the advantage of leaving both the bottom and the top edges of the nuts perfectly clean, without any ragged edge to be taken off afterwards by touching up with a file. The same was the case with the six edges at the angles of the nuts, which were finished perfectly true and smooth by the cutters, in consequence of the cutters being arranged so as to overlap one another in their cut at the edges of the hexagon. In the case of nuts made as usual with the top edge chamfered off,

the nuts were threaded upon the mandril alternately top and bottom upwards, so as to get the flat bottoms contiguous, and ensure the bottom edges being finished clean, without any arris being left on. The specimens of nuts exhibited were all just as they came from the machine, the cutters having passed only once over them, leaving all the edges finished perfectly smooth and clean. In the working of the machine the cutters were either kept at work continuously both in the upward and the downward traverse of the feed table, by supplying a fresh mandril full of nuts at each end of the traverse, so as to avoid any loss of time; or the cutters might be in action during one traverse only, the feed table being then run back empty in the return stroke, if there was not work enough to keep the machine fully occupied in both traverses.

The Chairman enquired whether in grinding the cutters they had to be ground at the sides as well as on the front edge; and whether there was any difficulty in readjusting the cutters to their correct position after grinding any one of them.

Mr. F. F. Smith replied that the cutters were ground only on the front edge, and did not require grinding at the sides, so that their width was not affected by the grinding. They all lasted about the same time in work, and when one of the six required grinding the rest were also about ready to be ground, the amount of work done by each of them being the same. The cutters were all adjusted to their correct position by setting them up to a steel collar slipped upon the mandril for the purpose, which served as an exact gauge for the diameter of the finished work; this was the only operation that required any care, but it was very easily done, and without any loss of time. As soon as the machine was set to work it required very little attention; one boy could look after two of the machines, and do all that was required in changing the mandrils for keeping the machines supplied with work. No time was lost in changing the mandrils, a fresh supply of nuts being got ready on a spare mandril to replace the finished set delivered from the machine at the end of each course. Before tightening up the nuts upon the mandril by the end lock-nut, the mandril was laid down upon a table, so as to bring all the flat faces of the nuts into line.

Mr. E. A. Cowper enquired whether the action of the cutters in revolving had not a tendency to rotate the mandril or the nuts on the mandril, as he supposed it was necessary for all the cutters to revolve in the same direction, in order that the adjacent ones might miss each other in their revolution.

Mr. Batho replied that that was the case, and the mandril was therefore prevented from turning by being fixed into a square socket in the feed table. The nuts that were being shaped were prevented from being carried round upon the plain mandril under the action of the cutters, by screwing up the end lock-nut tight enough to fix them securely.

The Chairman considered the machine now described would prove a valuable one in practice, and of great advantage for performing the very useful work of shaping nuts.

He proposed a vote of thanks to Mr. Batho for his paper, which was passed.

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A paper was then read "On Le Chatelier's plan of using Counter-pressure Steam as a Break in Locomotive Engines," by Mr. C. William Siemens, of London; and the discussion was adjourned to the next meeting. (See Proceedings January 1870.)

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The Meeting then terminated.

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